NASA TN D-390

TECHNICAL NOTE

D-390

AERODYNAMIC CHARACTERISTICS OF A 1/4-SCALE MODEL OF

A TILT-WING VTOL AIRCRAFT AT HIGH ANGLES

OF WING INCIDENCE

By Louis P. Tosti

Langley Research Center
Langley Field, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON September 1960

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-390

AERODYNAMIC CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT-WING VTOL AIRCRAFT AT HIGH ANGLES OF WING INCIDENCE

By Louis P. Tosti

SUMMARY

A force-test investigation has been made in the Langley full-scale tunnel to determine the stability and control characteristics of a 1/4-scale model of a tilt-wing vertical-take-off-and-landing aircraft in the transition flight range at high wing incidences. The model had two propellers with hinged (flapping) blades mounted on the wing which could be tilted up to an incidence angle of 86° for vertical take-off and landing.

Longitudinal stability data were obtained for wing incidences from 60° to 84° in a steady-level-flight condition. Lateral stability and aileron and rudder control data were obtained for wing incidences from 60° to 80° for conditions of steady level flight (zero acceleration), 0.25g forward acceleration, and 0.25g deceleration. The data are presented without analysis.

INTRODUCTION

An investigation is being conducted to determine the stability and control characteristics of a 1/4-scale model of the Vertol 76 (VZ-2) vertical-take-off-and-landing (VTOL) aircraft. The results of flight tests of this model are presented in reference 1. Force tests in the hovering, transition, and forward-flight ranges are reported in reference 2. The force tests in the transition-flight range were made for wing incidences from 20° to 80° in increments of 20°. These force tests indicated that large changes in forces and moments probably occurred in the range of wing incidence from 60° to 80°. Since the full-scale aircraft encountered some lateral stability and control difficulties in this range of wing incidence, it was decided to obtain additional data with more closely spaced wing-incidence increments. The additional tests reported in the present paper include lateral stability and control tests in the high wing-incidence range in

5° increments for conditions simulating steady level flight (zero acceleration), 0.25g forward acceleration, and 0.25g deceleration. Longitudinal stability characteristics are presented in the high wing-incidence range for steady level flight. Longitudinal characteristics were also obtained for 70° wing angle of attack for various wing incidences and tail incidences.

SYMBOLS

The force-test data of the model are referred to the stability system of axes. Figure 1 shows these axes and the positive directions of the forces, moments, and angular displacements.

The definitions of the symbols used in the present paper are as follows:

F'_D	drag, lb
F_L	lift, lb
F_Y	lateral force, lb
g	acceleration due to gravity, ft/sec^2
i_t	horizontal-tail incidence, positive trailing edge down, deg
i_w	wing incidence, deg
M_{X_S}	rolling moment, ft-lb
M_{Y_S}	pitching moment, ft-lb
M_{Z_S}	yawing moment, ft-lb
V	equivalent velocity of full-scale aircraft, knots
X_s,Y_s,Z_s	stability axes
α	angle of attack of fuselage, deg
β	angle of sideslip, deg

δ_a differential aileron control deflection, $\delta_a{}'_R - \delta_a{}'_L$, deg

$\delta_a{}'_L$ deflection of left aileron, positive trailing edge down, deg

$\delta_a{}'_R$ deflection of right aileron, positive trailing edge down, deg

δ_r deflection of rudder, positive trailing edge left, deg

ϕ angle of roll, deg

MODEL

The model used in the investigation was the 1/4-scale flying model of the Vertol 76 (VZ-2) VTOL aircraft, which was used in the free-flight tests of reference 1. Figure 2 shows a three-view drawing of the model and table I presents the geometric characteristics scaled up to the full-size-aircraft values. The model had two 3-blade propellers with flapping hinges and was powered by a 6-horsepower electric motor which drove the propellers through shafting and right-angle gear boxes. The speed of the motor was changed to vary the thrust of the propellers. The propeller blade angle was set at 12°.

The wing was pivoted at the 37-percent mean-aerodynamic-chord station and could be rotated to provide incidence angles from 4° to 86°. The model had an all-movable horizontal tail and conventional aileron and rudder controls for forward flight. The hovering-flight controls were not hooked up for these model tests. For pitch and yaw control in the hovering-flight tests of reference 1, the model had provision for jet-reaction controls in the rear of the fuselage instead of the recessed tail "fans" in the horizontal and vertical tails which are used on the aircraft; the tail fans were not represented in the model tests.

TESTS

The tests were made in the Langley full-scale tunnel with the model support strut mounted near the lower edge of the entrance cone and about 5 feet above a ground board. Electric strain-gage balances were used to measure the forces and moments on the model, and an electric tachometer was used to set the various model propeller speeds needed in the tests. Blockage and interference effects in the tunnel were believed to be very small and, therefore, no wind-tunnel corrections were applied to the data.

Longitudinal stability characteristics were determined for wing incidences of 60°, 65°, 70°, 75°, 80°, and 84° for zero acceleration at zero angle of attack. The tests were made at angles of attack between -10° and 30°.

Longitudinal aerodynamic data were obtained for fuselage angles of attack of -10°, 0°, 10°, and 20° with wing incidences set to give a constant wing angle of attack of 70° relative to the wind for each of these settings. The 70° wing angle of attack was arbitrarily chosen to obtain the effect of fuselage angle of attack on the pitching moment of the model at essentially constant airspeed. It should be noted that the algebraic sum of the fuselage angle of attack and the wing incidence equaled the wing angle of attack which was held constant at 70°. For each of the four conditions set up, the horizontal-tail incidence was varied from -20° to 20°.

Lateral stability and control were determined for wing incidences of 60°, 65°, 70°, 75°, and 80°. The tests were made with power settings which, with the fuselage at zero angle of attack and the controls neutral, gave 0.25g forward acceleration, zero acceleration, and 0.25g deceleration. With these power settings, the angle of sideslip was varied from 20° to -20°, the aileron-effectiveness tests were made for a range of deflection of the right aileron from 30° to -30°, and the rudder-effectiveness tests were made for a range of rudder deflection from 0° to -30°.

To represent the power conditions of the full-scale aircraft at high angles of wing incidence, it was necessary to use tunnel airspeeds of 11.7 knots and lower to avoid exceeding the motor limitations of the model. The effective Reynolds number based on the wing chord and the maximum free-stream velocity used in the tests was about 150,000.

PRESENTATION OF RESULTS

The data have been scaled up to the same weight and center-of-gravity locations of the full-scale aircraft as those used in reference 2. These conditions are shown in the present paper in table II.

The longitudinal aerodynamic characteristics of the model are presented in figures 3 and 4; the lateral stability and aileron and rudder control characteristics are presented in figures 5 to 11. Since there is considerable scatter of the data in the figures, particularly at the higher wing incidences, caution should be used in selecting individual points or curves for use in analysis. The data are presented in the figures as shown in the following table:

CONCLUDING REMARKS

The present paper presents the results of wind-tunnel tests of a 1/4-scale model of a tilt-wing vertical-take-off-and-landing aircraft. The data include longitudinal stability characteristics for the low-speed portions of the transition range from 60° to 84° wing incidence at zero acceleration and lateral stability and control characteristics for wing incidences from 60° to 80° for a range of conditions simulating zero acceleration, 0.25g forward acceleration, and 0.25g deceleration.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., February 26, 1960.

REFERENCES

1. Tosti, Louis P.: Flight Investigation of the Stability and Control Characteristics of a 1/4-Scale Model of a Tilt-Wing Vertical-Take-Off-and-Landing Aircraft. NASA MEMO 11-4-58L, 1959.

2. Newsom, William A., Jr., and Tosti, Louis P.: Force-Test Investigation of the Stability and Control Characteristics of a 1/4-Scale Model of a Tilt-Wing Vertical-Take-Off-and-Landing Aircraft. NASA MEMO 11-3-58L, 1959.

TABLE I.- SCALED-UP GEOMETRIC CHARACTERISTICS OF THE MODEL

Propellers (3 blades each rotor):	
Diameter, ft	9.33
Solidity	0.239
Chord, ft	1.0
Wing:	
Pivot station, percent chord	37
Sweepback (leading edge), deg	0
Airfoil section	NACA 4415
Aspect ratio	5.42
Chord, ft	4.75
Taper ratio	1.0
Area, sq ft	118.2
Span, ft	24.88
Dihedral angle, deg	0
Ailerons (each):	
Chord, ft	1.22
Span, ft	4.83
Hinge line, percent chord	74.1
Vertical tail:	
Sweepback (leading edge), deg	0
Airfoil section	NACA 0012
Aspect ratio	1.25
Chord, ft	4.0
Taper ratio	1.0
Area, sq ft	20
Span, ft	5.0
Rudder (hinge line perpendicular to fuselage center line):	
Chord, ft	1.25
Span, ft	5.0
Horizontal tail:	
Sweepback (leading edge), deg	0
Airfoil section	NACA 0012
Aspect ratio	3.10
Chord, ft	3.0
Center-section chord, ft	4.21
Area (including center body), sq ft	29.70
Span, ft	9.90
Dihedral angle, deg	0

TABLE II.- CENTER-OF-GRAVITY LOCATIONS FOR FULL-SCALE AIRCRAFT AT VARIOUS WING-INCIDENCE ANGLES

[Weight, 3,139 lb]

i_w, deg	Center-of-gravity location (from wing pivot), ft	
	Horizontal (forward)	Vertical (below)
50	0.346	1.082
55	.320	1.066
60	.297	1.057
65	.270	1.042
70	.240	1.032
75	.213	1.026
80	.180	1.023
84	.157	1.022

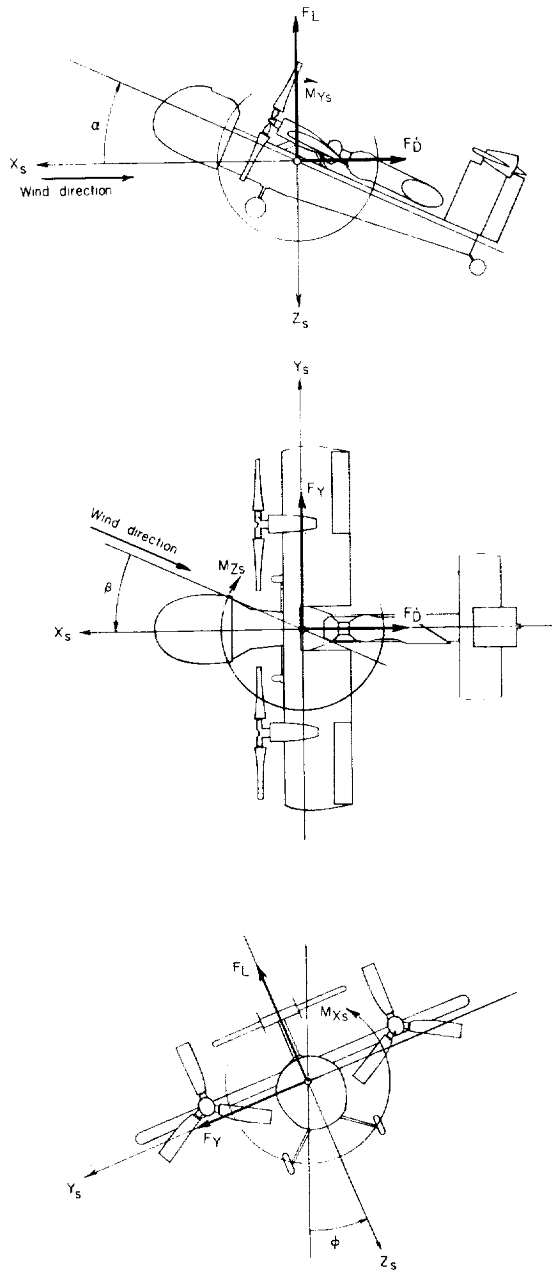


Figure 1.- Stability system of axes. Arrows indicate positive directions of forces, moments, and angular displacements. This system of axes is defined as an orthogonal system having the origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.

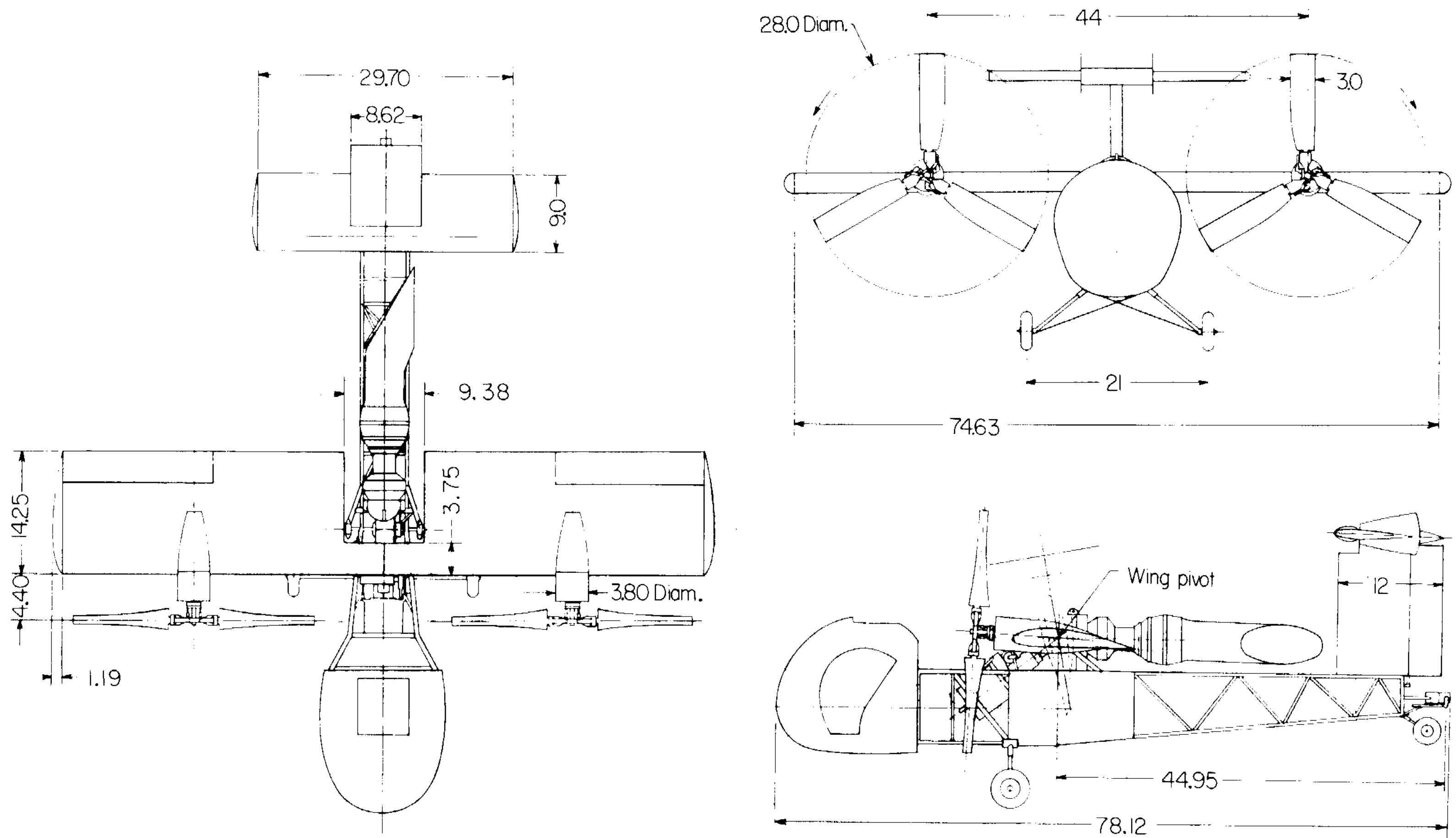


Figure 2.- Three-view sketch of model. All dimensions are in inches.

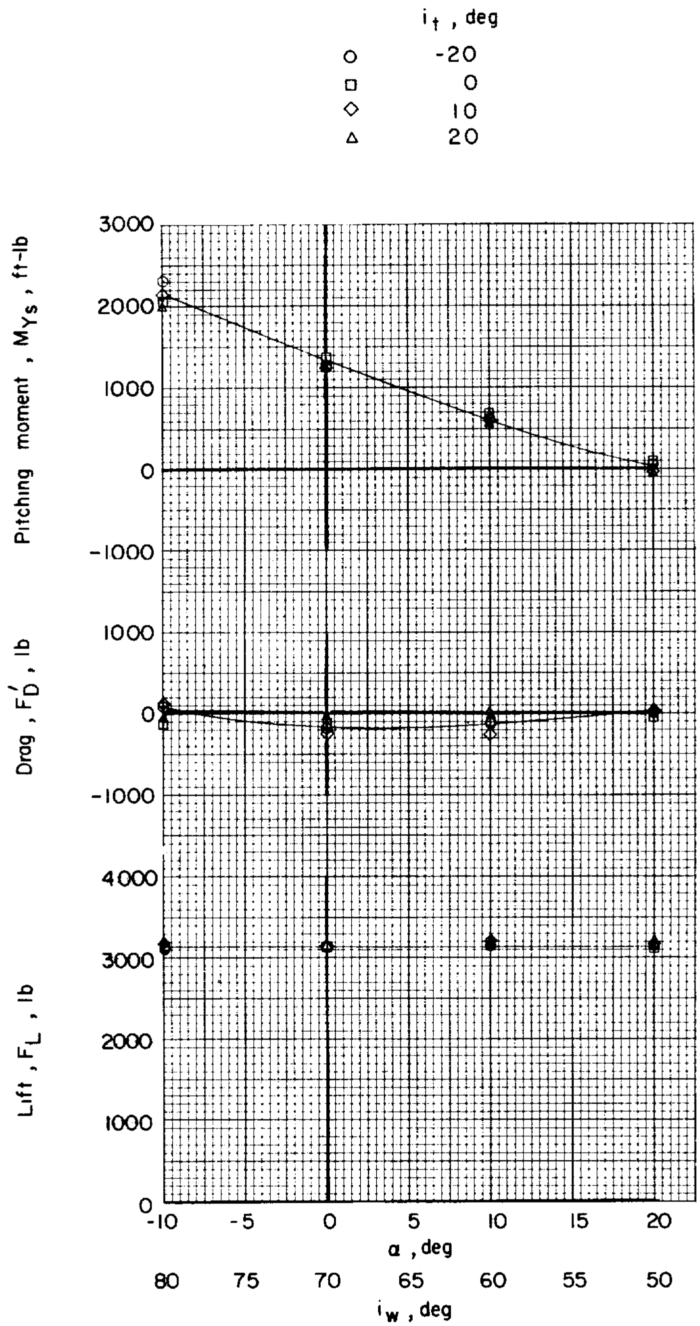


Figure 3.- Longitudinal aerodynamic characteristics at 70° wing angle of attack for various wing incidences and tail incidences. $V = 20.7$ knots; $\delta_a = \delta_r = \beta = 0^\circ$.

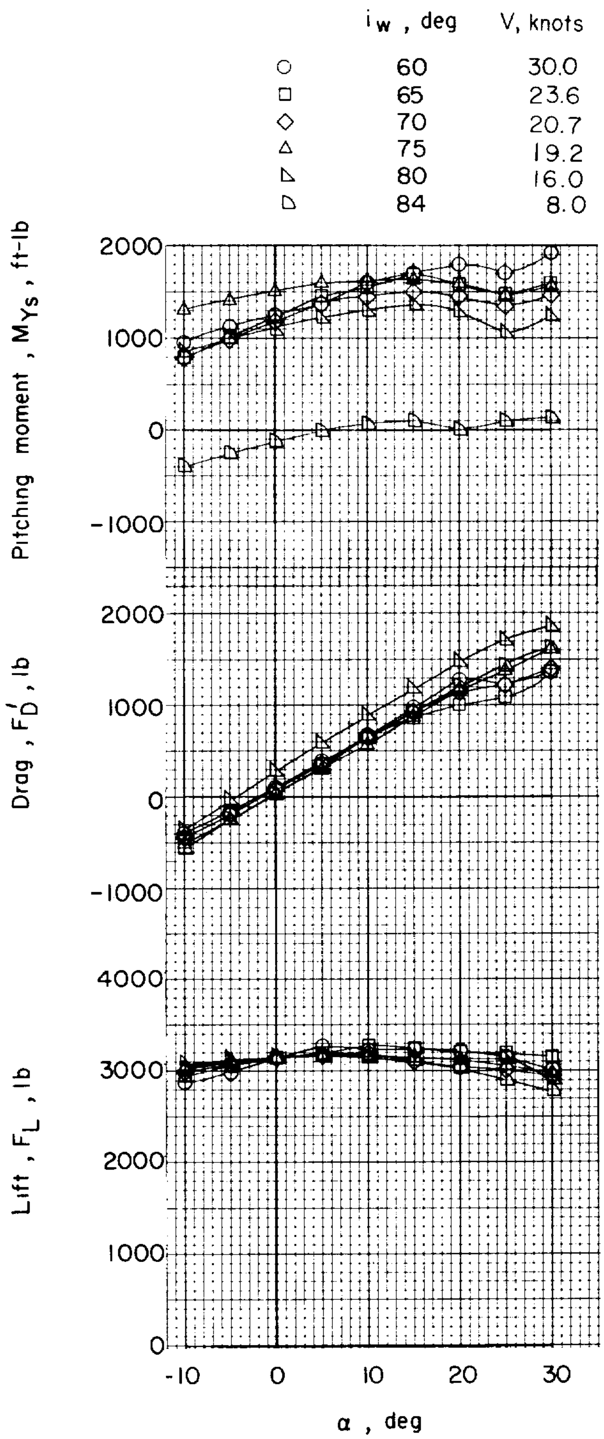
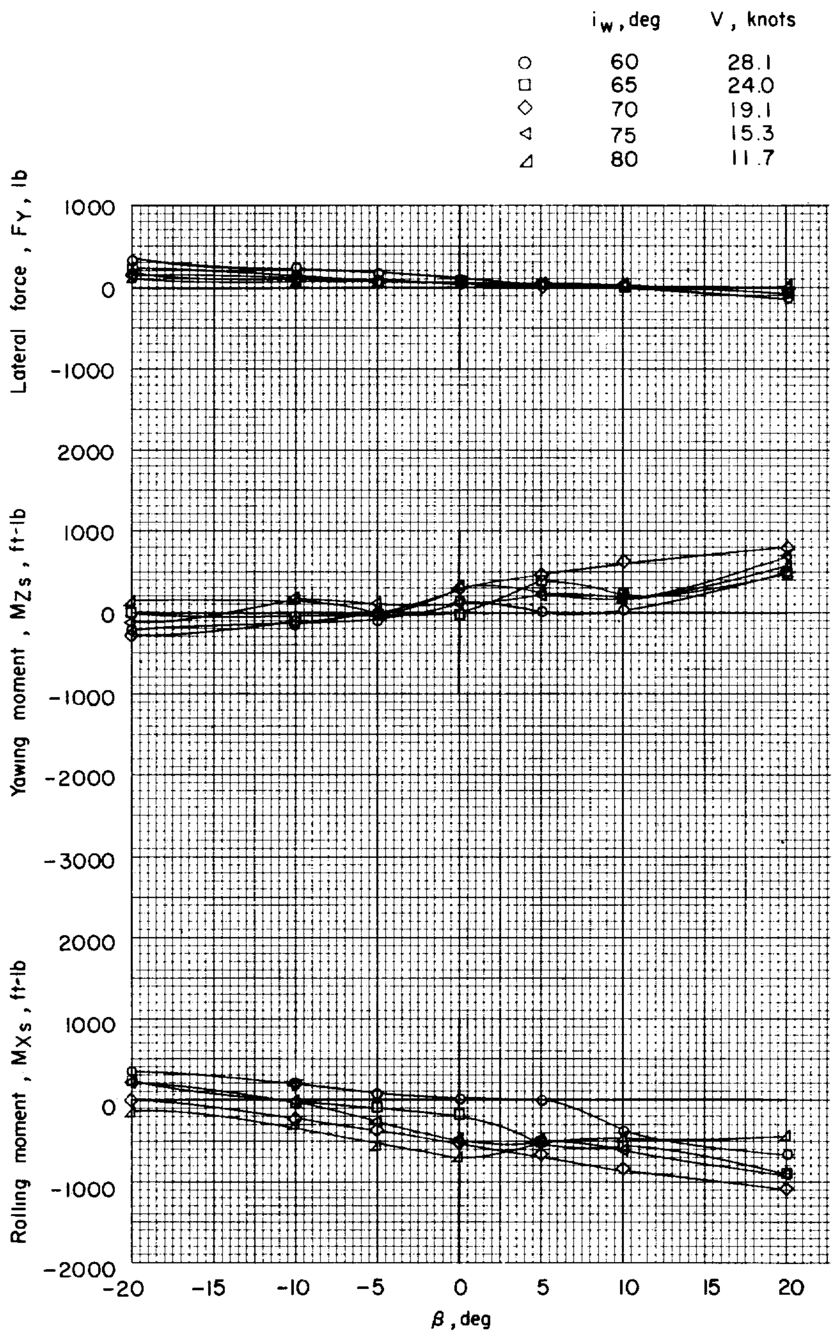
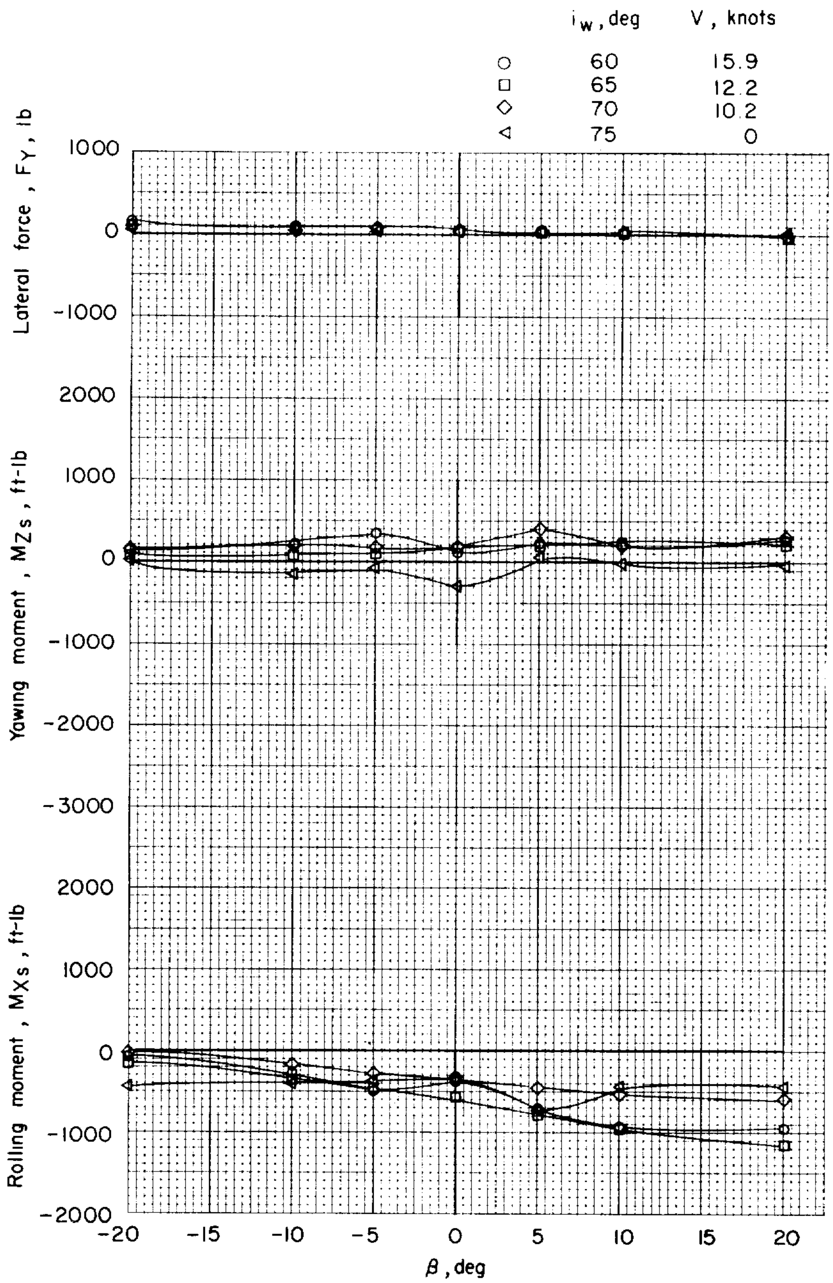


Figure 4.- Longitudinal stability characteristics for zero acceleration at $\alpha = 0^{\circ}$.



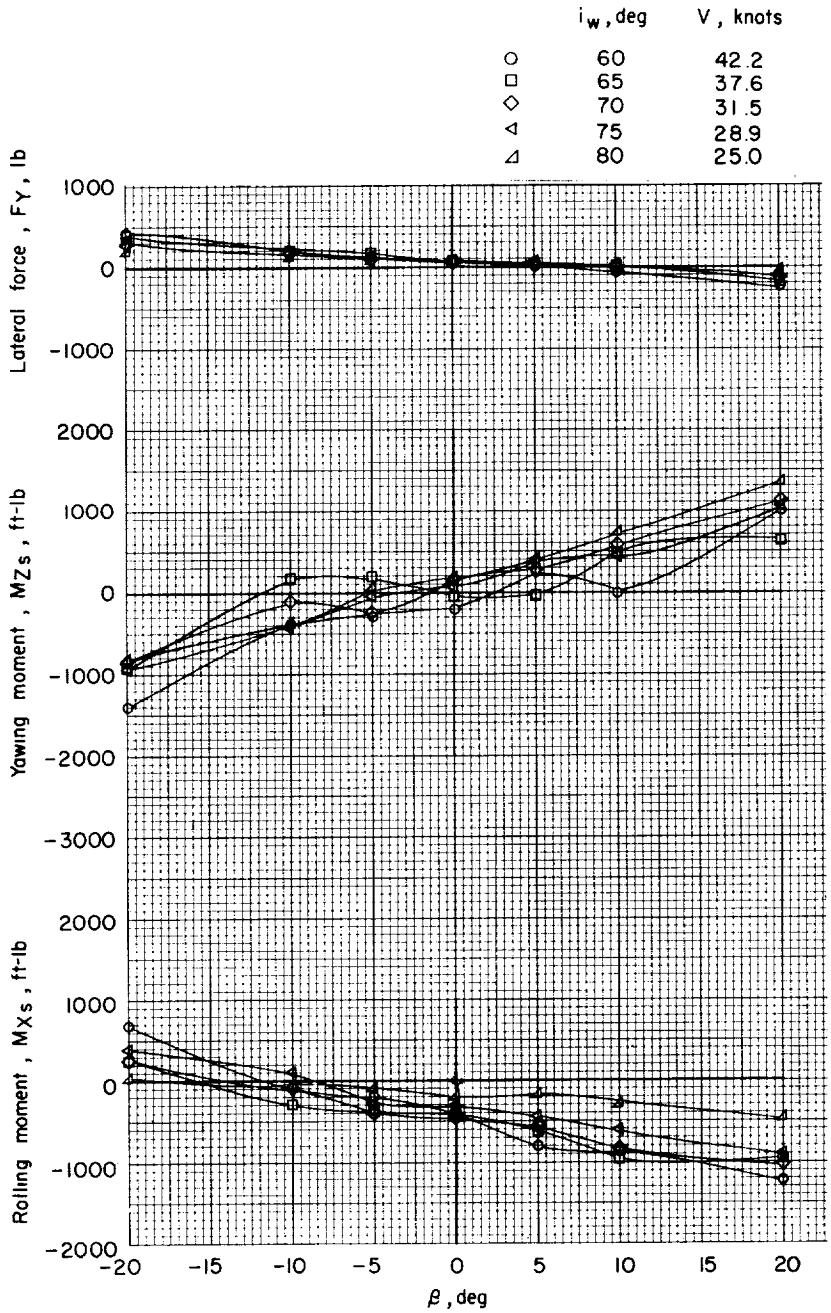
(a) Zero acceleration at $\beta = 0^{\circ}$.

Figure 5.- Lateral stability characteristics. $\delta_a = \delta_r = \alpha = 0^{\circ}$.



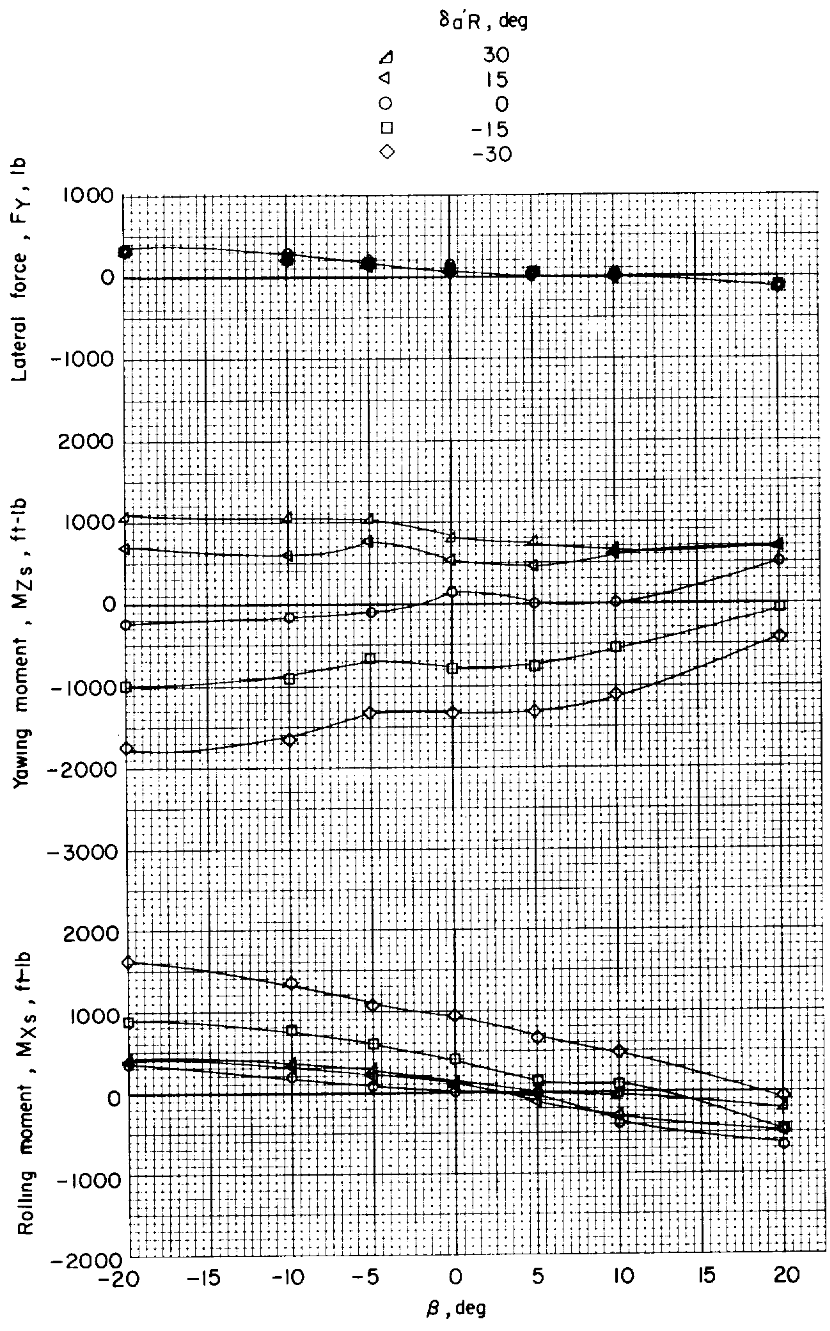
(b) 0.25g forward acceleration at $\beta = 0^{\circ}$.

Figure 5.- Continued.



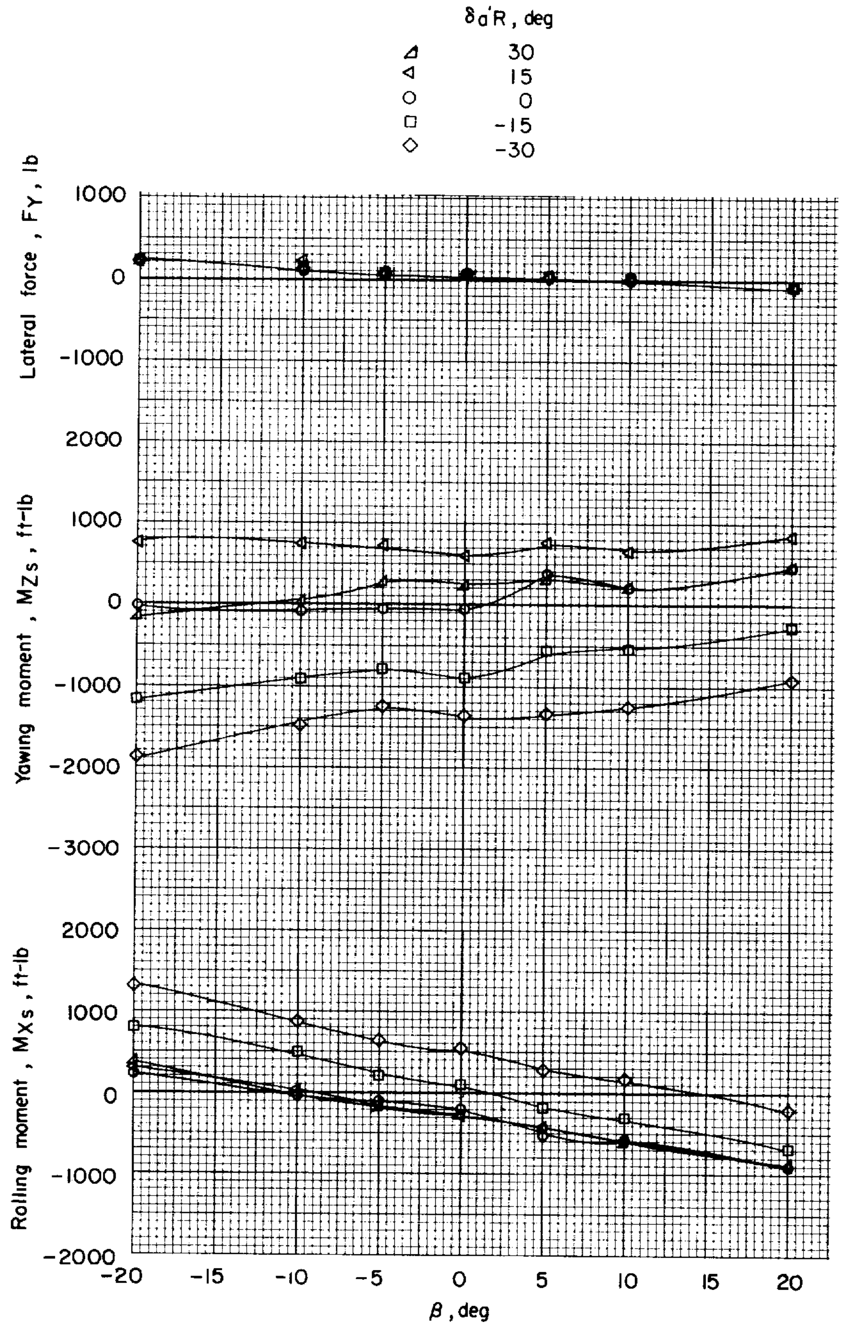
(c) 0.25g deceleration at $\beta = 0^{\circ}$.

Figure 5.- Concluded.



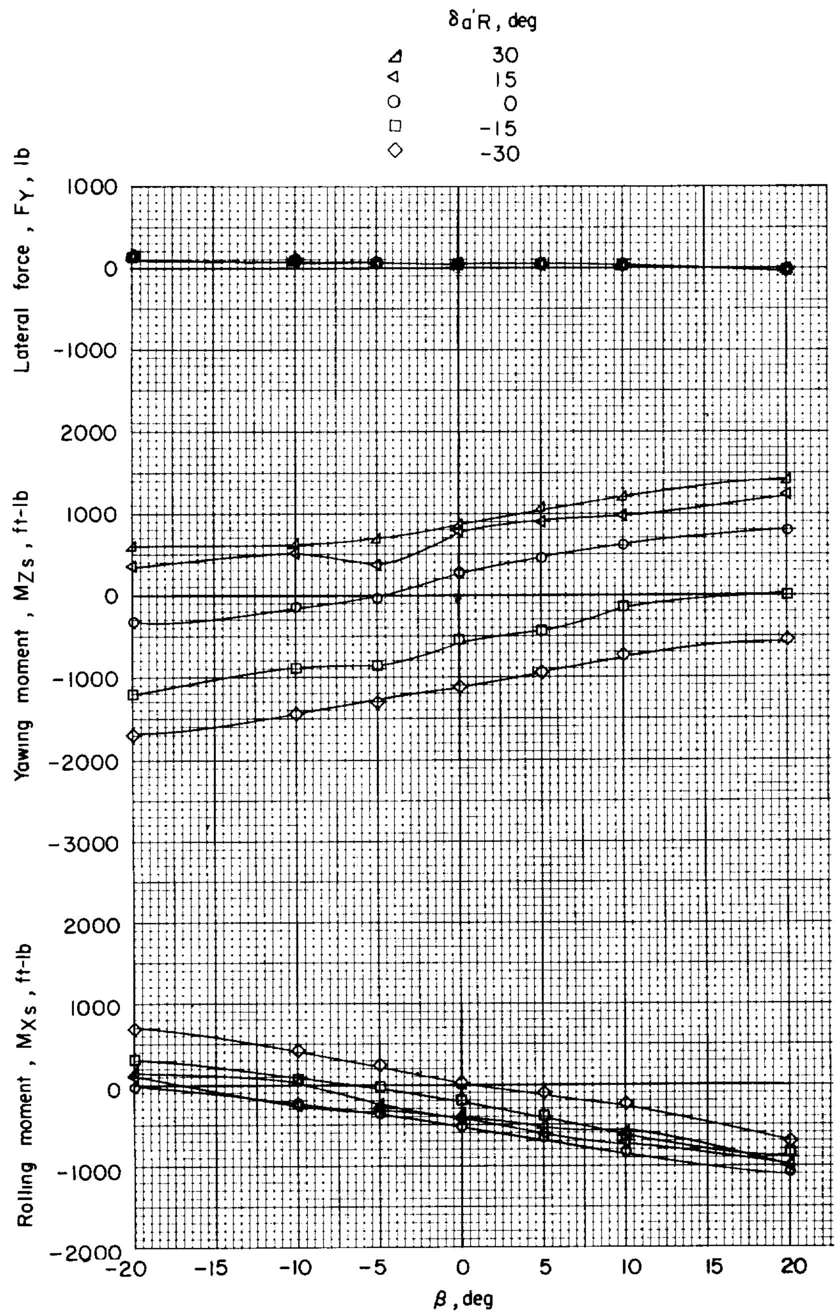
(a) $i_w = 60^\circ$; V = 28.1 knots.

Figure 6.- Lateral stability and aileron control characteristics for zero acceleration at $\beta = 0^\circ$. $\delta_a{}'_L = \delta_r = \alpha = 0^\circ$.



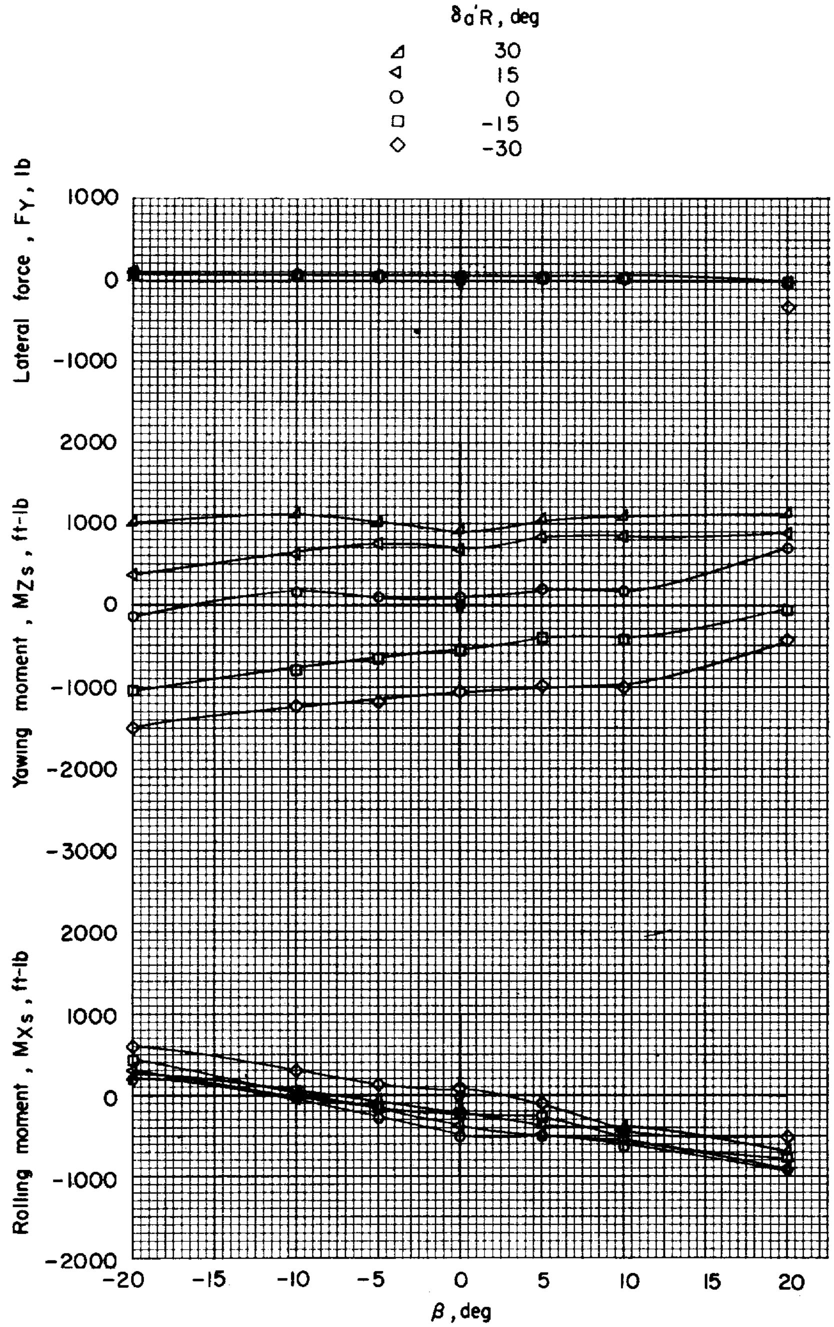
(b) $i_w = 65^o$; V = 24.0 knots.

Figure 6.- Continued.



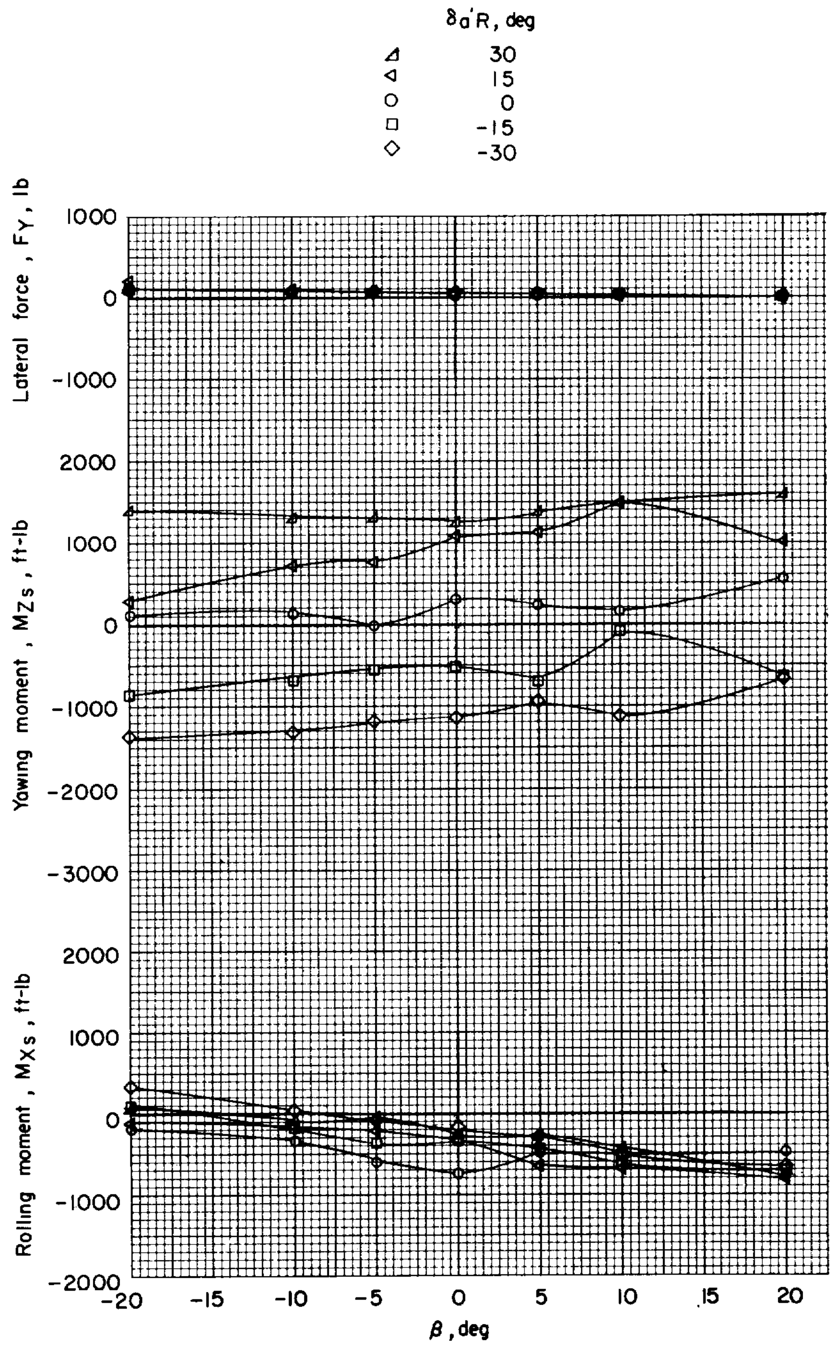
(c) $i_w = 70^o$; V = 19.1 knots.

Figure 6.- Continued.



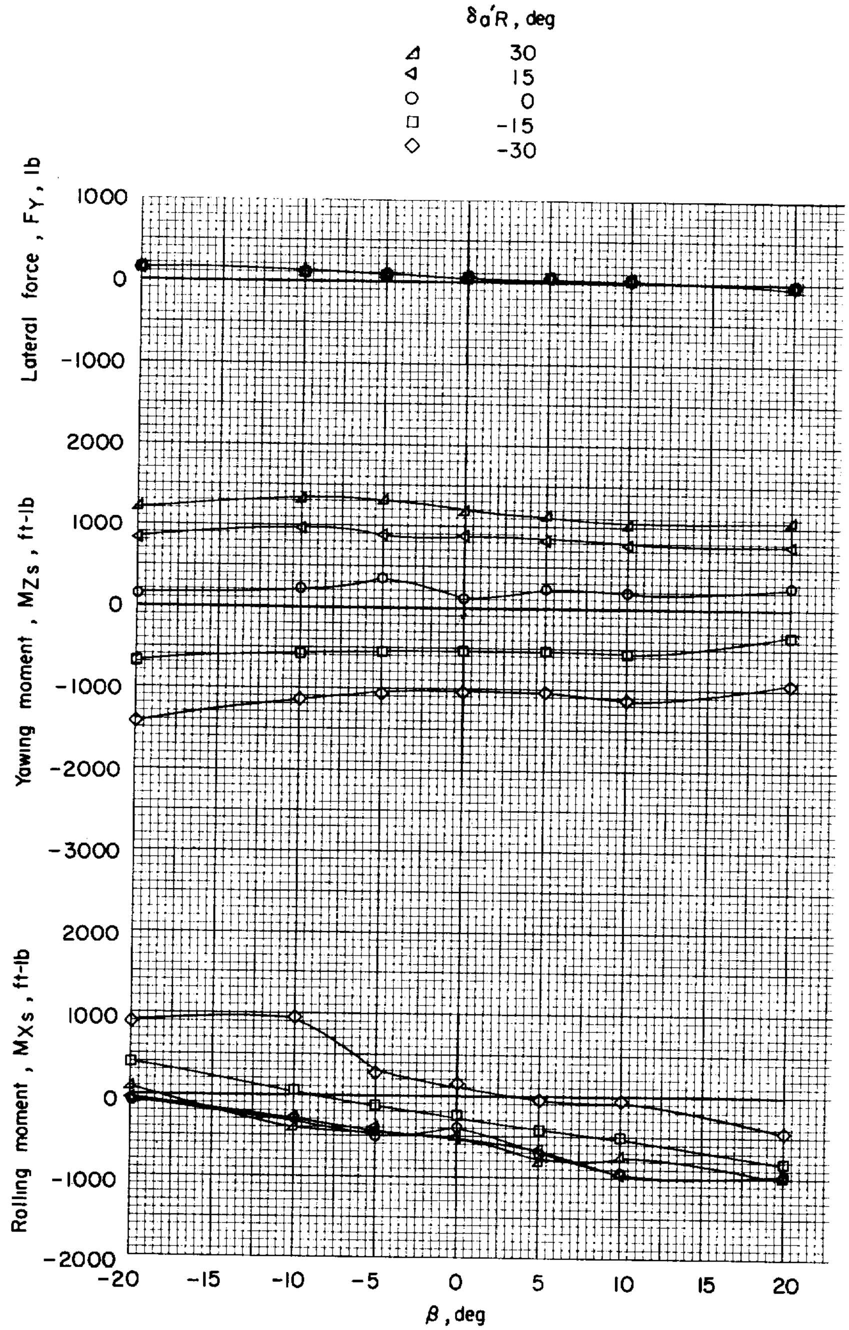
(d) $i_w = 75^{\circ}$; V = 15.3 knots.

Figure 6.- Continued.



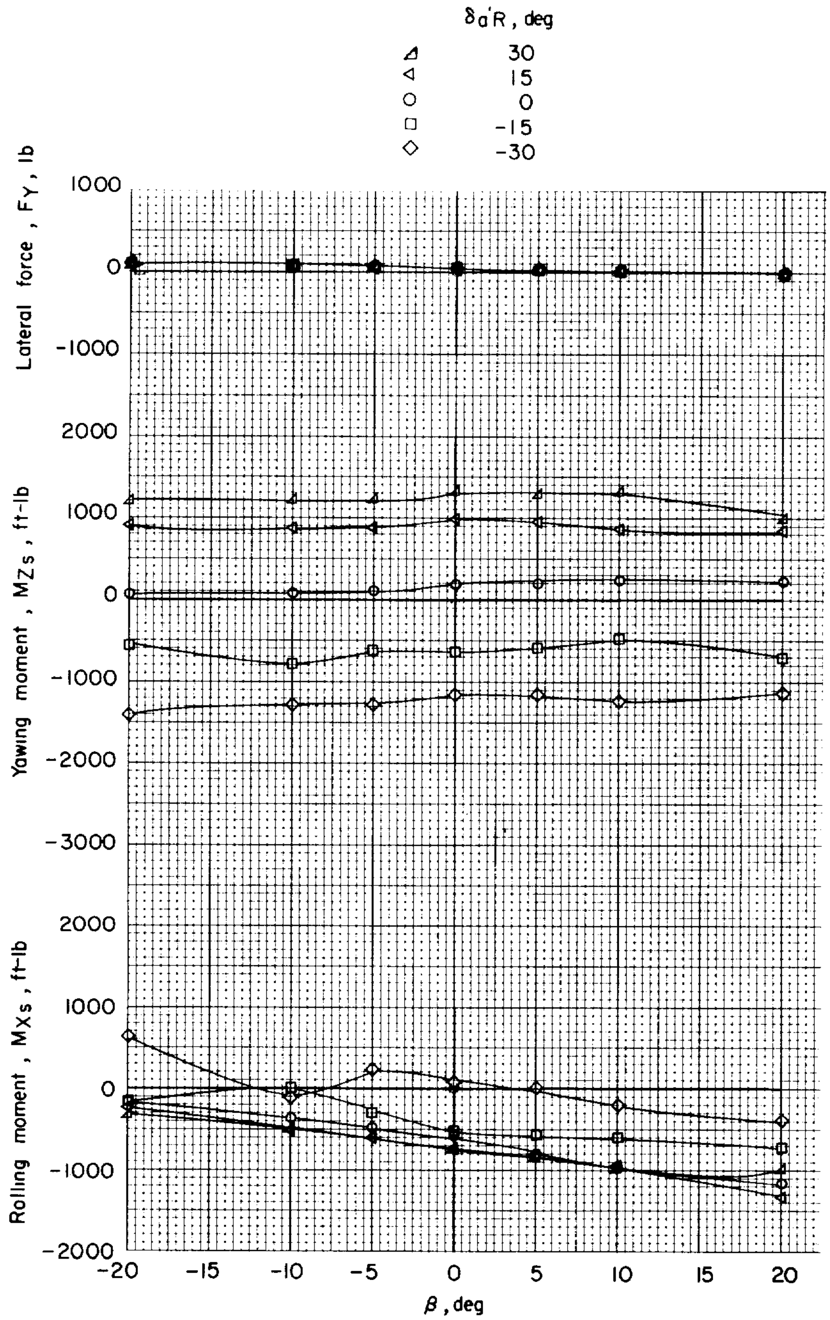
(e) $i_w = 80^o$; V = 11.7 knots.

Figure 6.- Concluded.



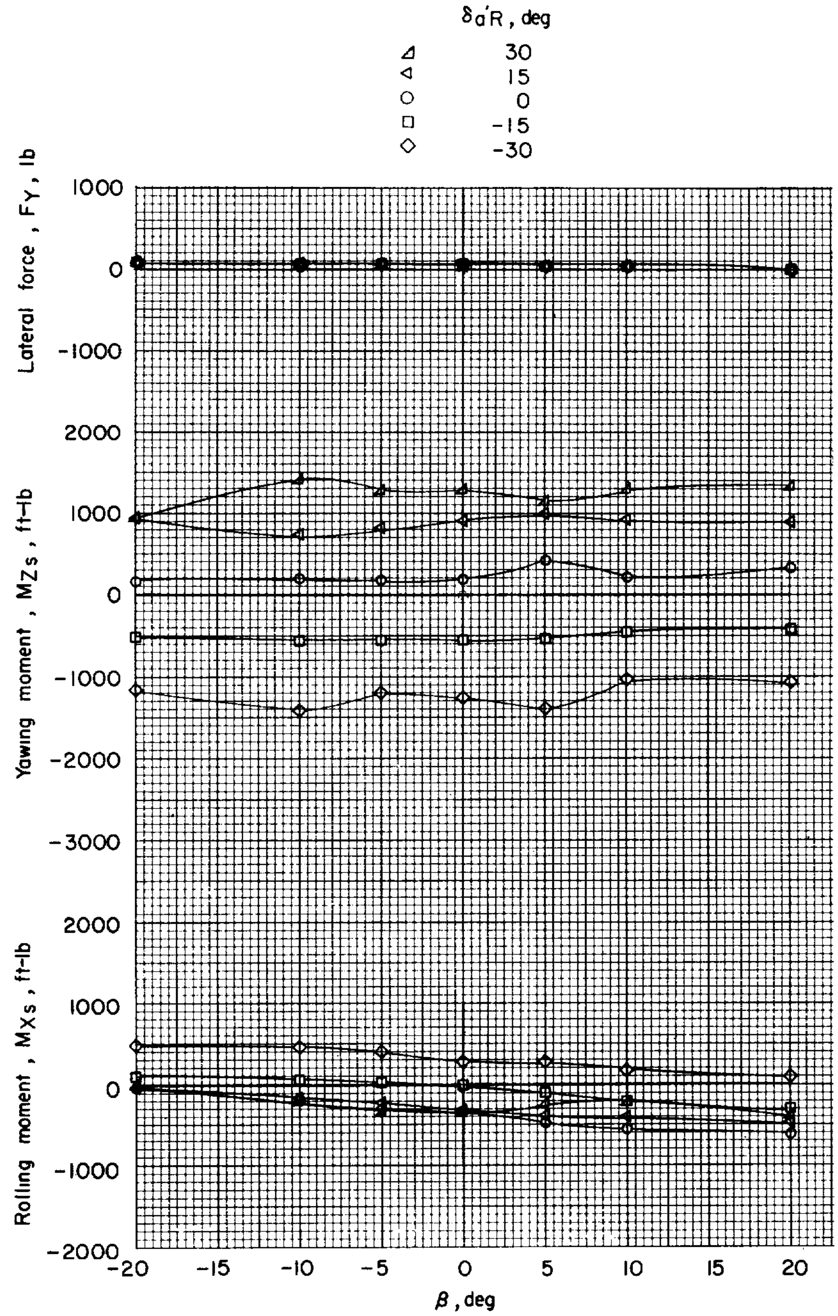
(a) $i_w = 60^o$; V = 15.9 knots.

Figure 7.- Lateral stability and aileron control characteristics for 0.25g forward acceleration at $\beta = 0^o$. $\delta_{a'L} = \delta_r = \alpha = 0^o$.



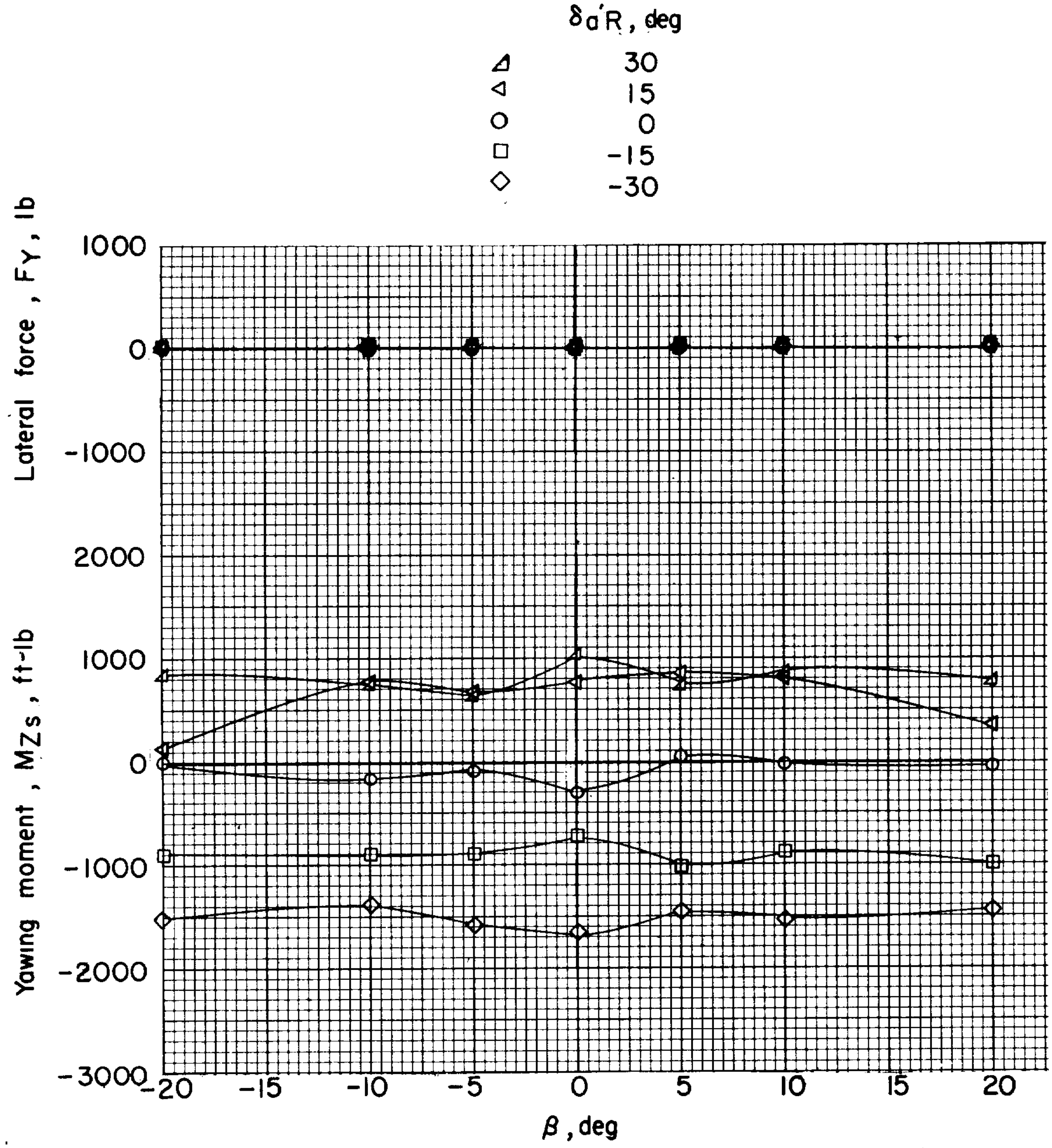
(b) $i_w = 65^o$; V = 12.2 knots.

Figure 7.- Continued.



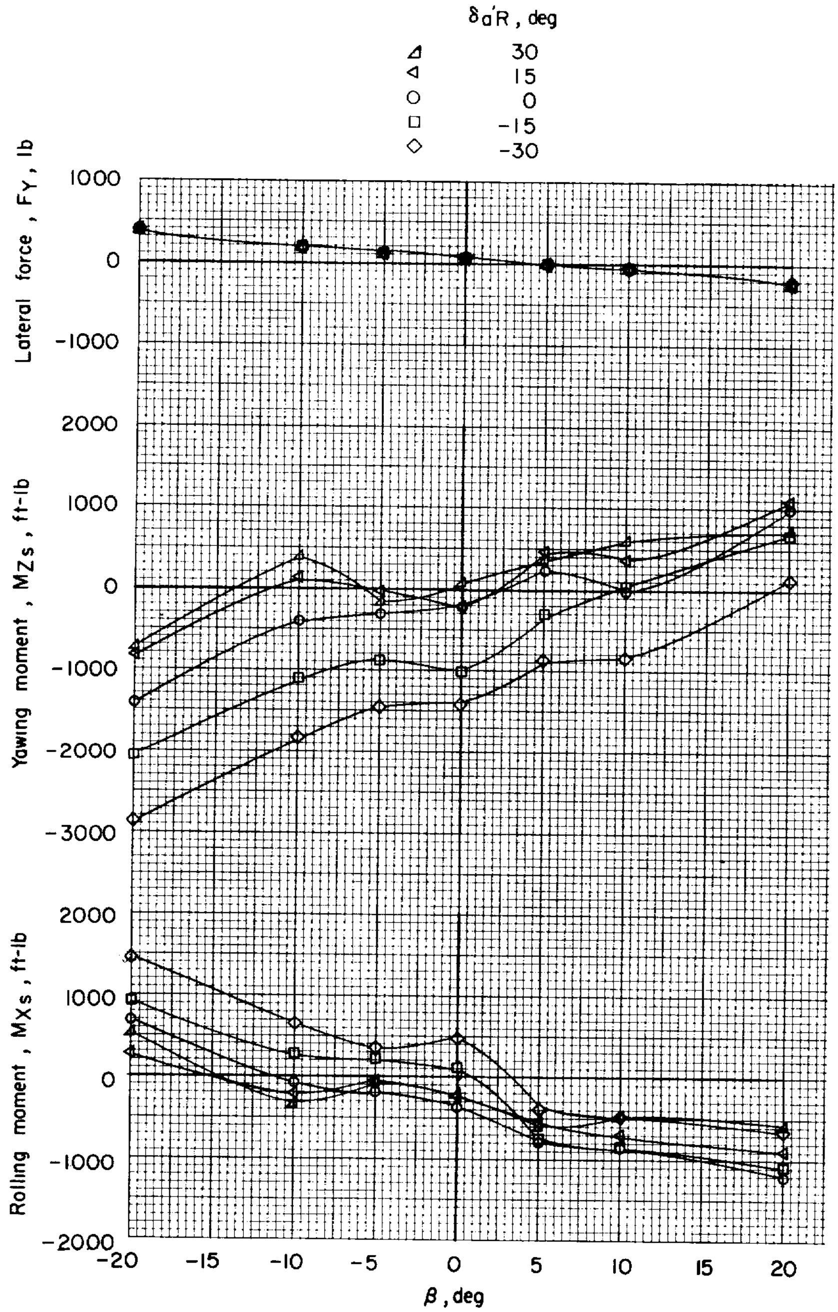
(c) $i_w = 70^{\circ}$; V = 10.2 knots.

Figure 7.- Continued.



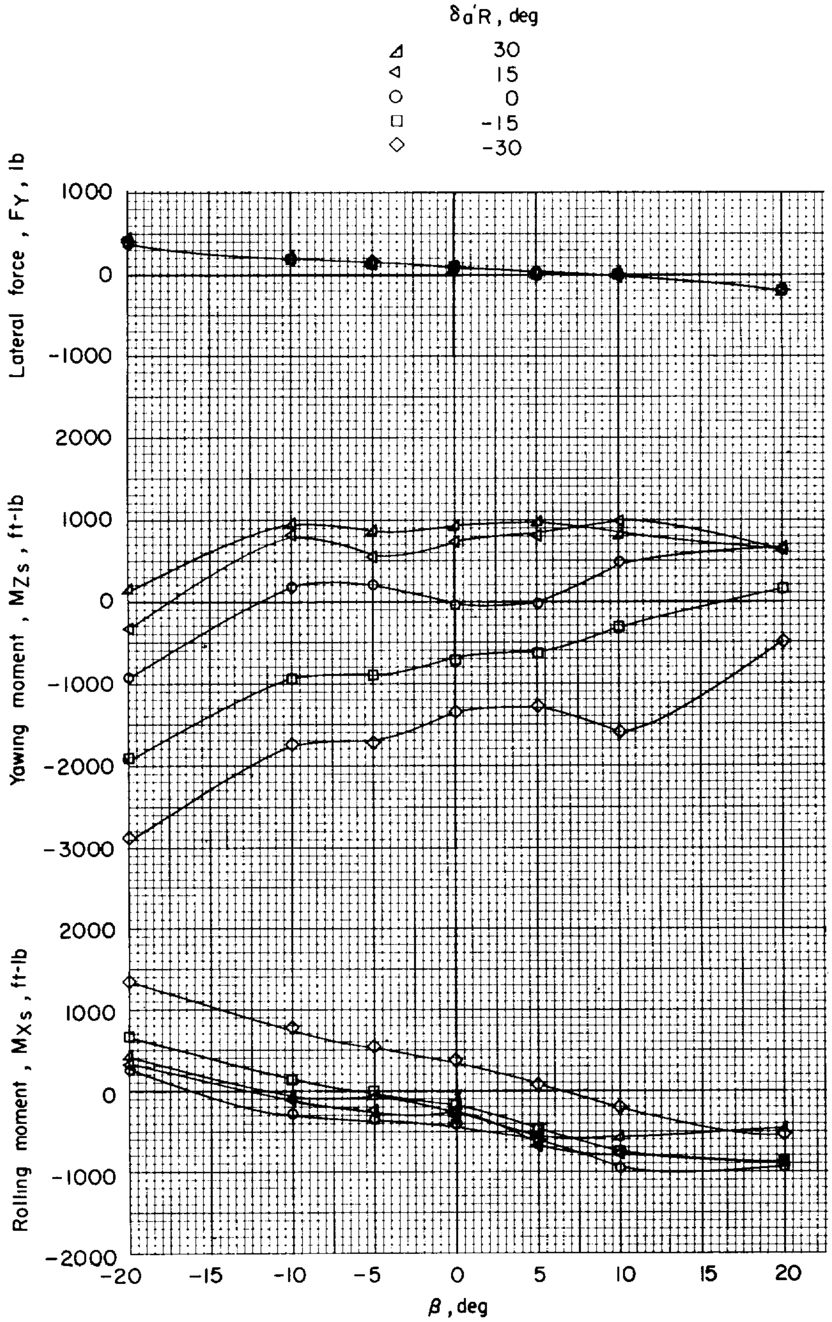
(d) $i_w = 75^o$; V = 0 knots.

Figure 7.- Concluded.



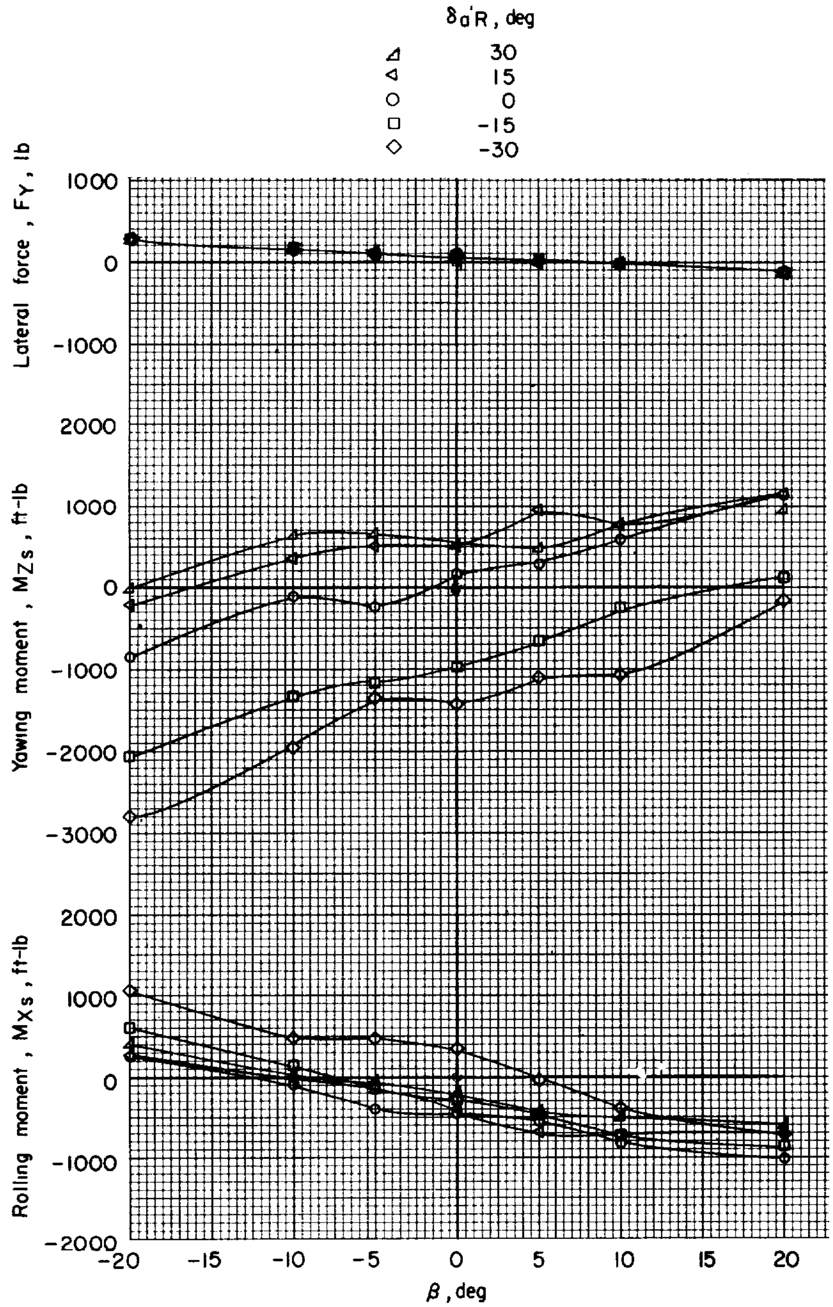
(a) $i_w = 60^{\circ}$; V = 42.2 knots.

Figure 8.- Lateral stability and aileron control characteristics for 0.25g deceleration at $\beta = 0^{\circ}$. $\delta_{a'L} = \delta_r = \alpha = 0^{\circ}$.



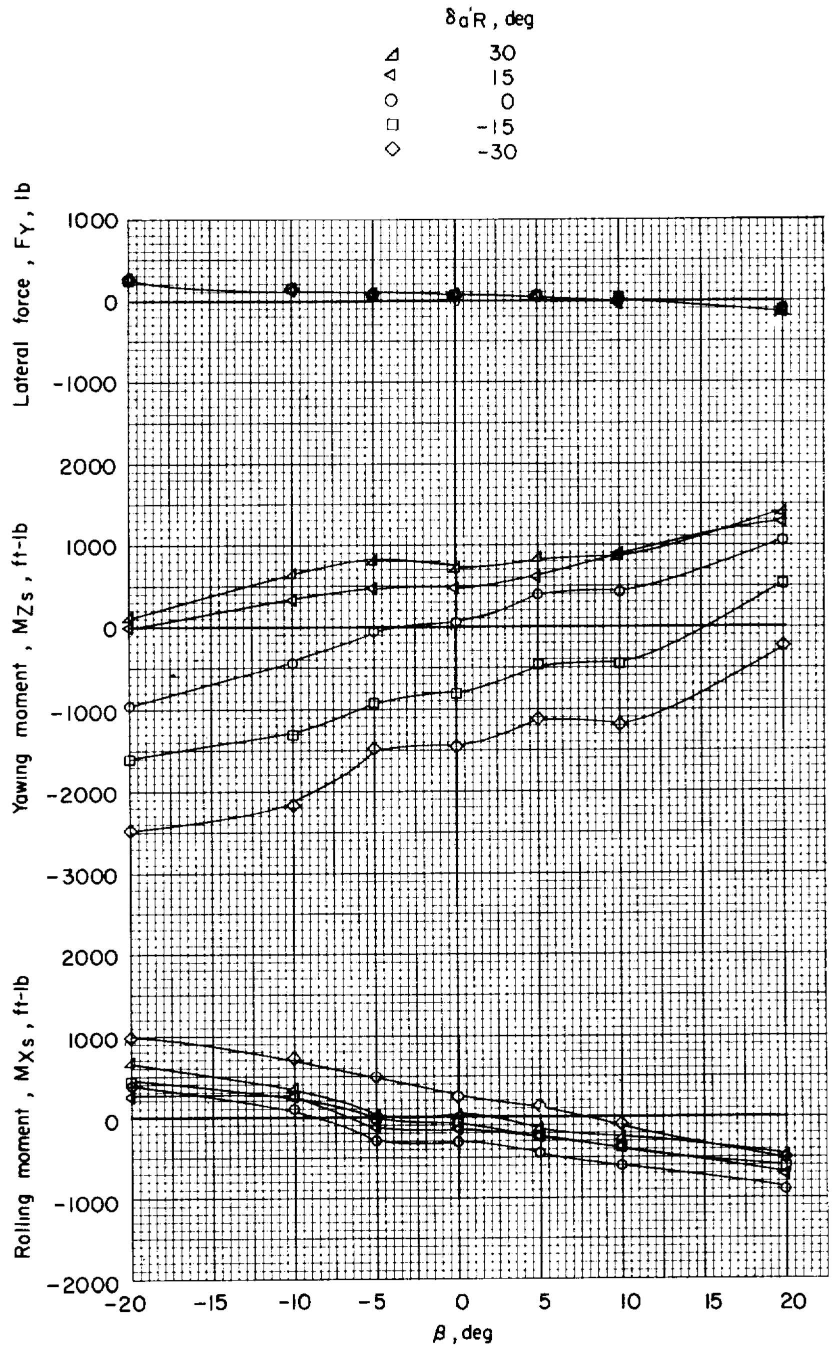
(b) $i_w = 65^{\circ}$; V = 37.6 knots.

Figure 8.- Continued.



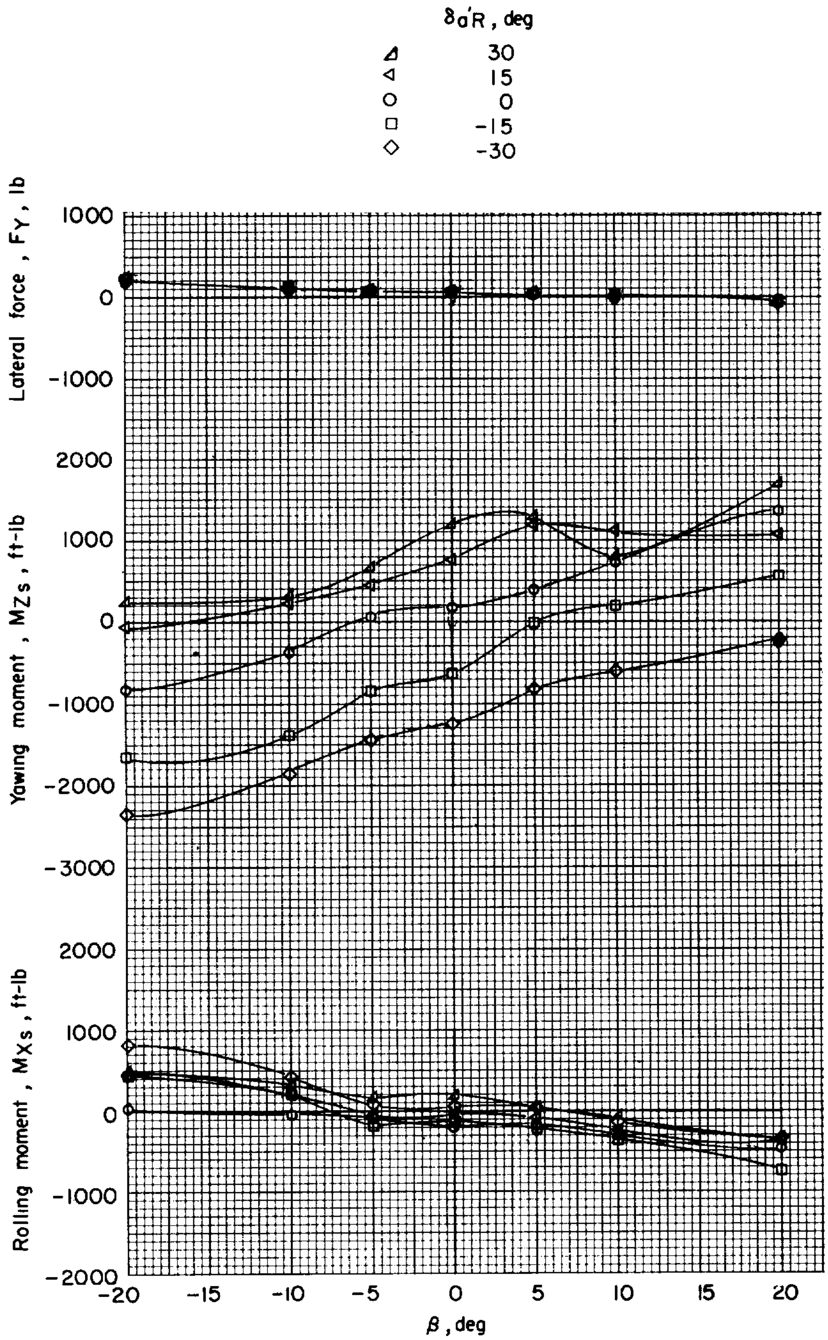
(c) $i_w = 70^{\circ}$; V = 31.5 knots.

Figure 8.- Continued.



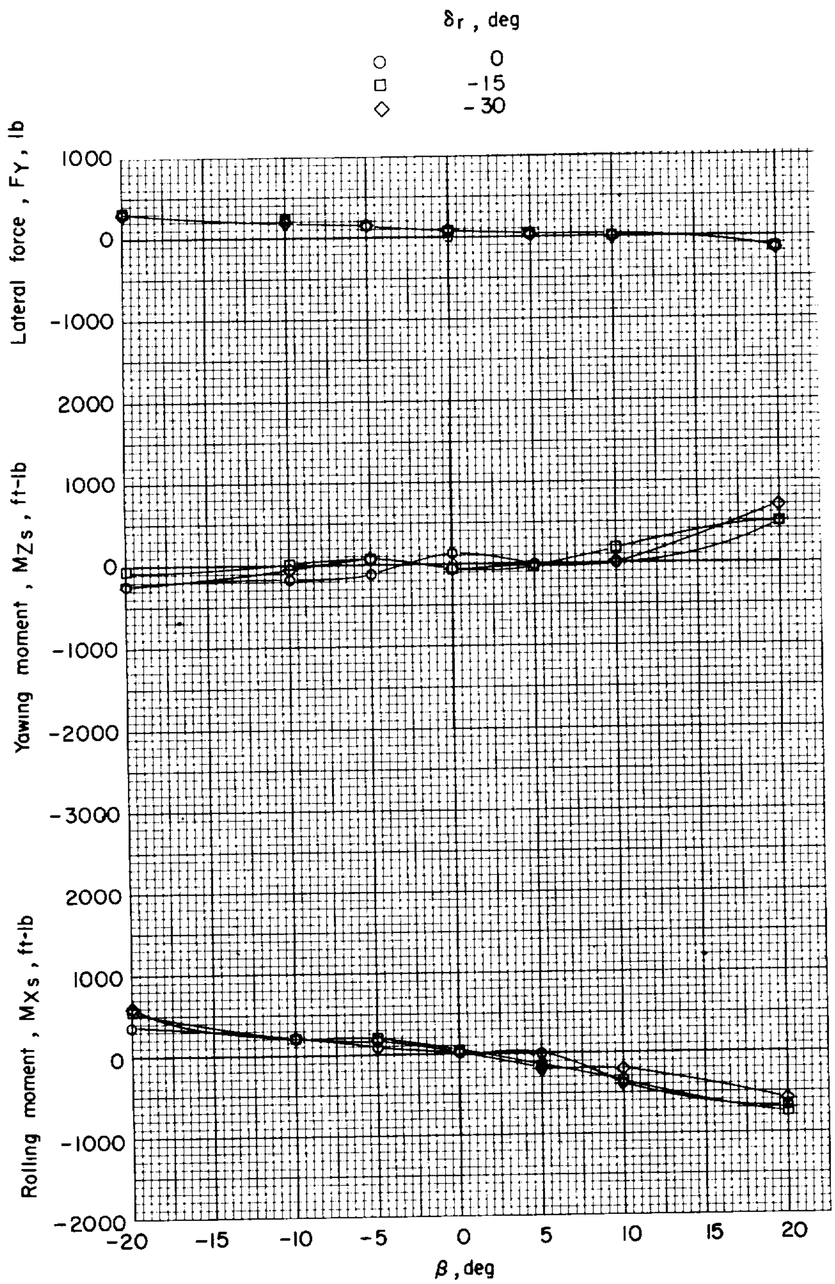
(d) $i_w = 75^\circ$; V = 28.9 knots.

Figure 8.- Continued.



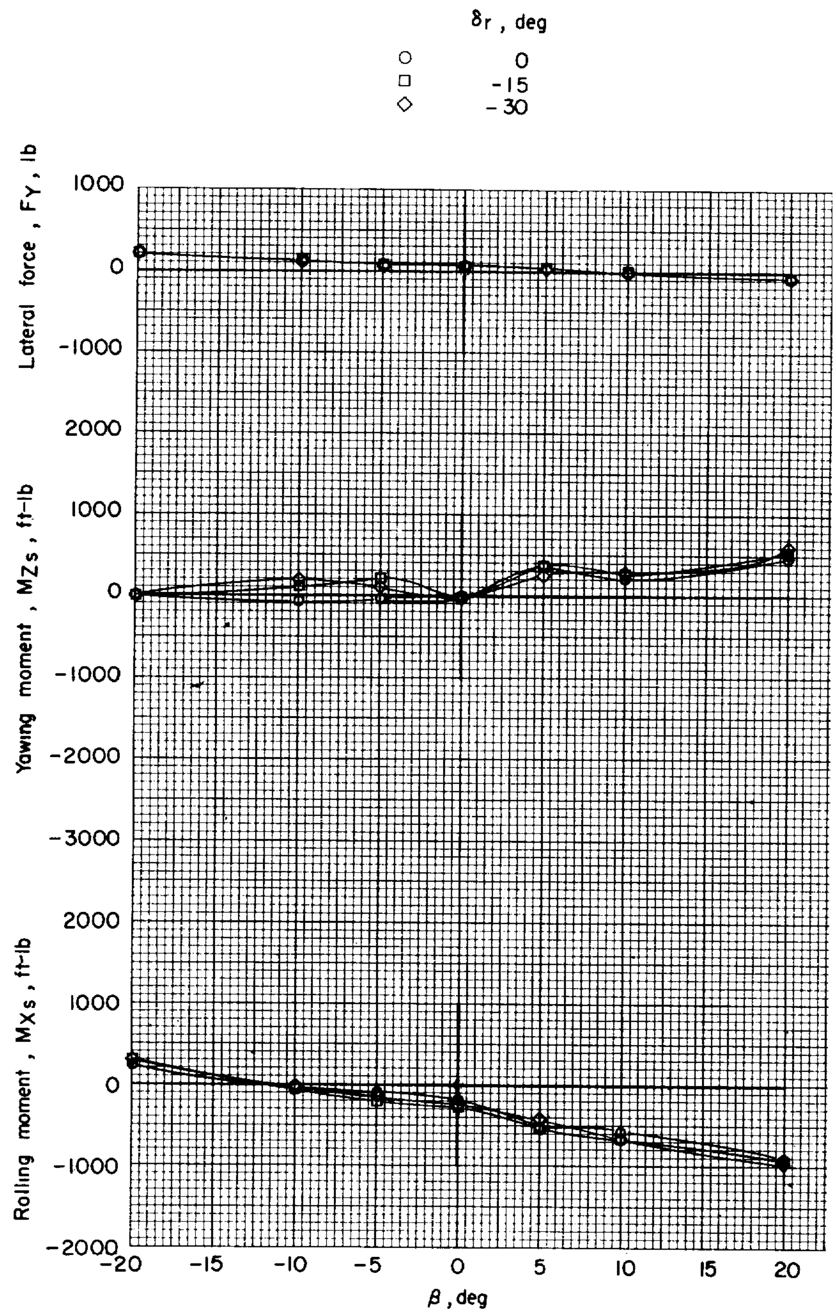
(e) $i_w = 80^o$; V = 25.0 knots.

Figure 8.- Concluded.



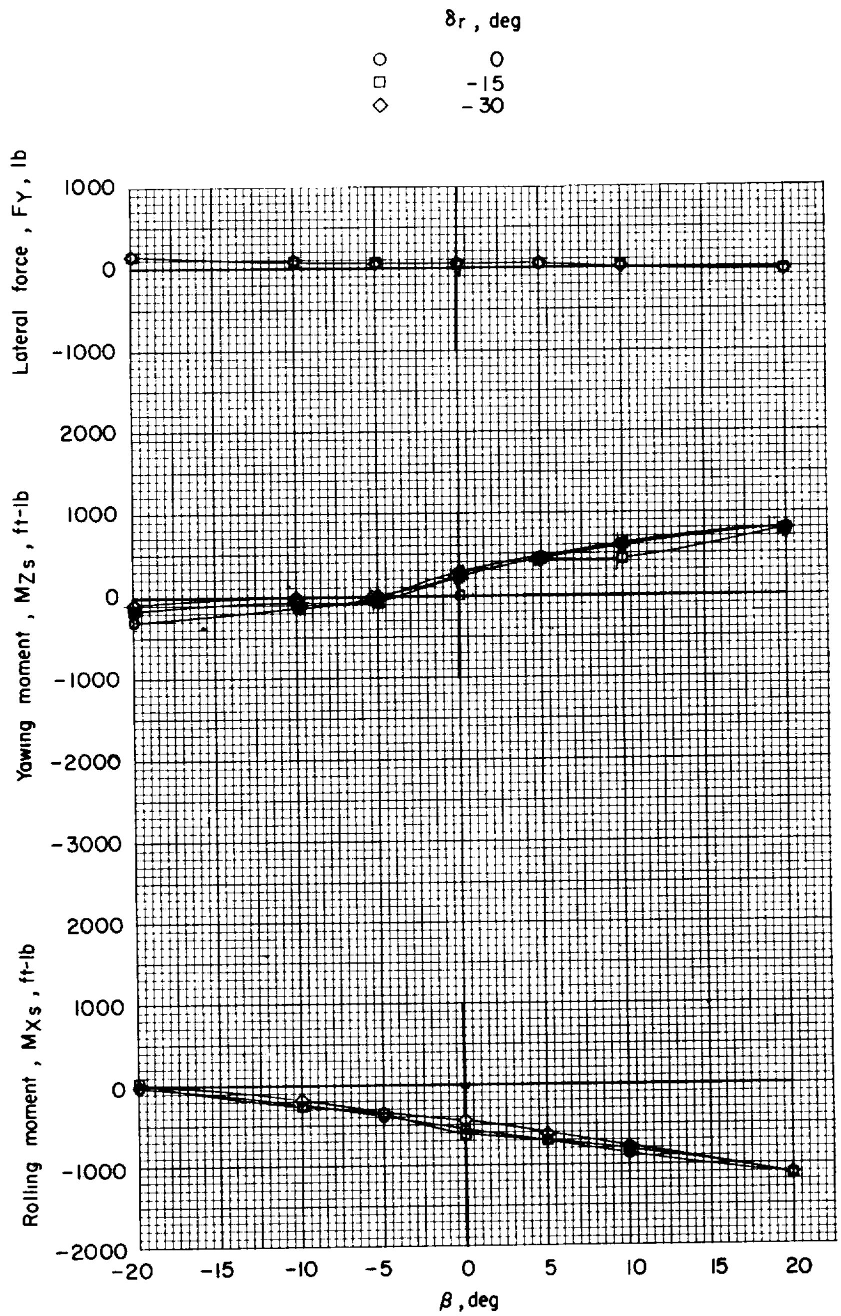
(a) $i_w = 60^\circ$; $V = 28.1$ knots.

Figure 9.- Lateral stability and rudder control characteristics for zero acceleration at $\beta = 0^\circ$. $\delta_a = \alpha = 0^\circ$.



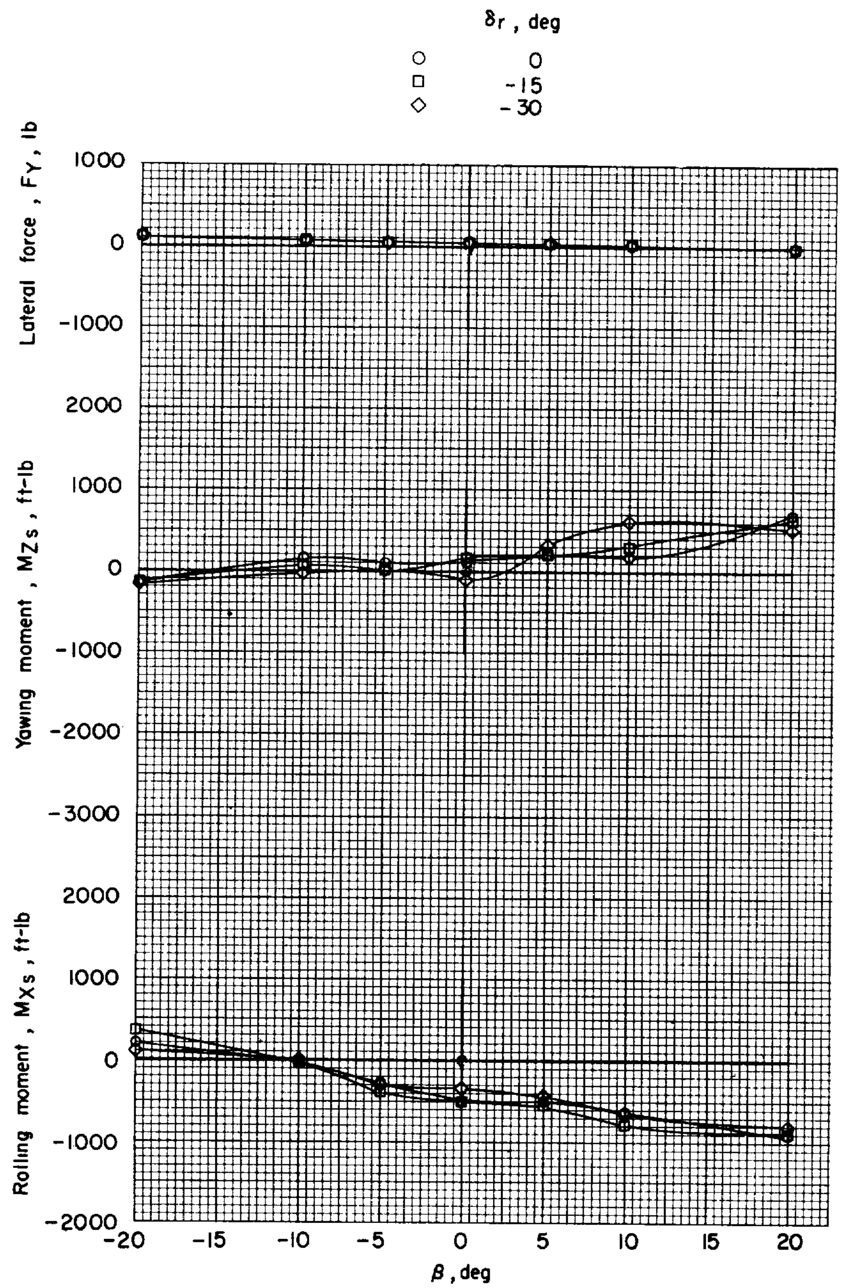
(b) $i_w = 65^{\circ}$; V = 24.0 knots.

Figure 9.- Continued.



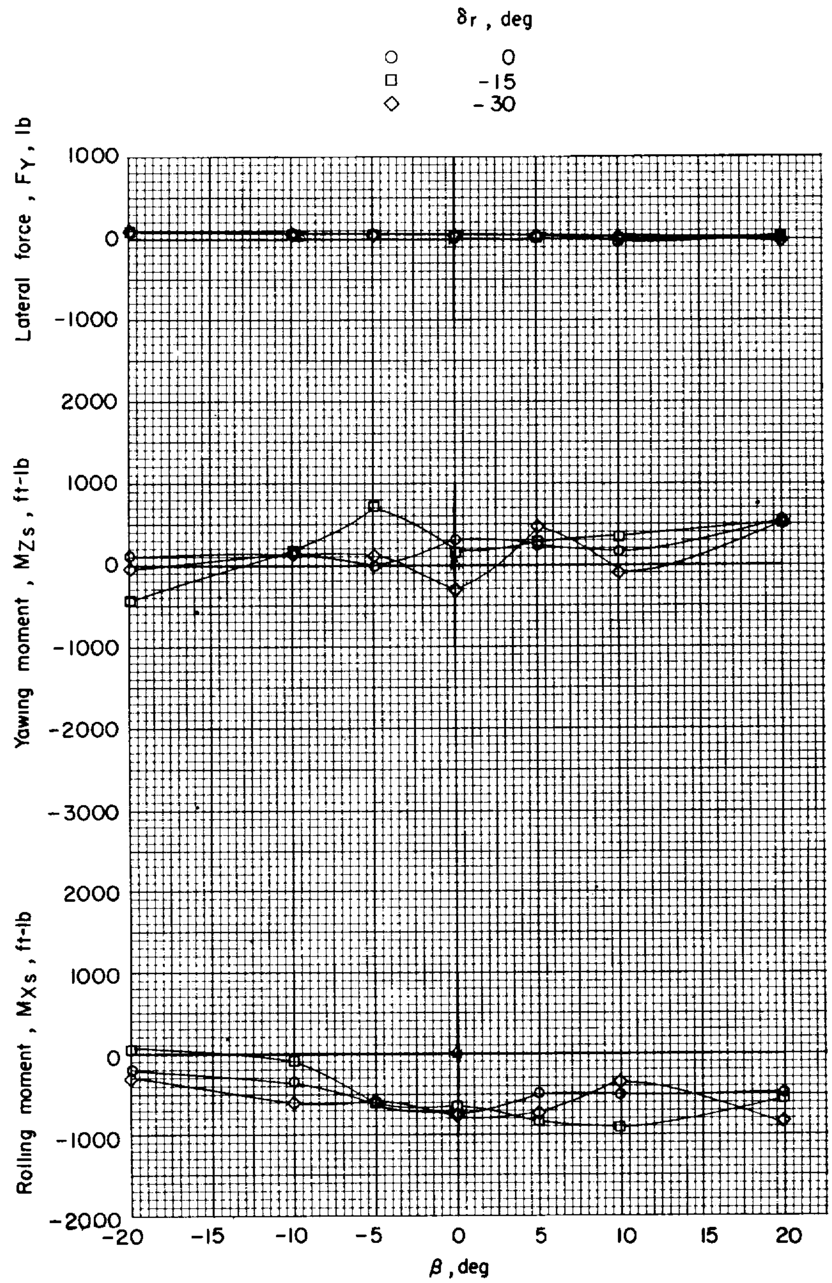
(c) $i_w = 70^{\circ}$; V = 19.1 knots.

Figure 9.- Continued.



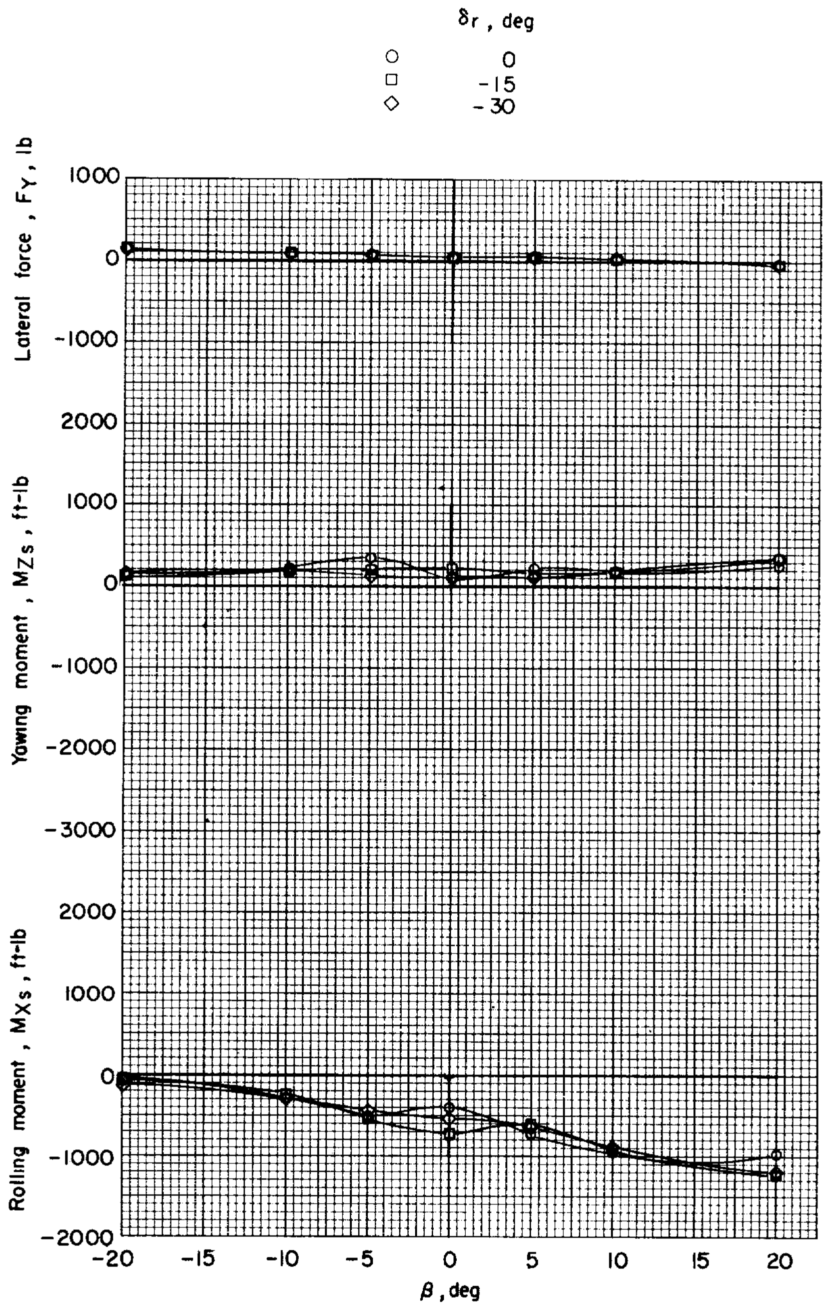
(d) $i_w = 75^o$; V = 15.3 knots.

Figure 9.- Continued.



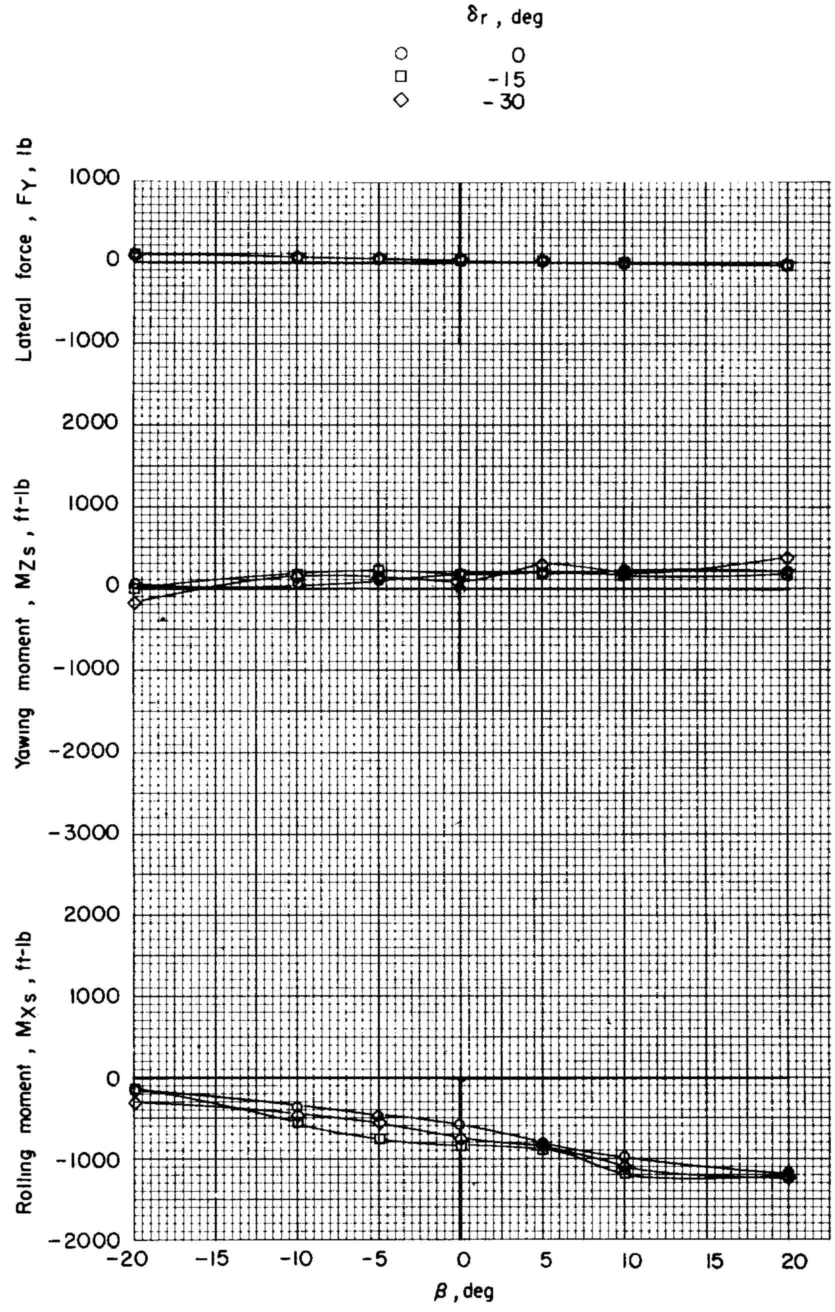
(e) $i_w = 80^\circ$; V = 11.7 knots.

Figure 9.- Concluded.



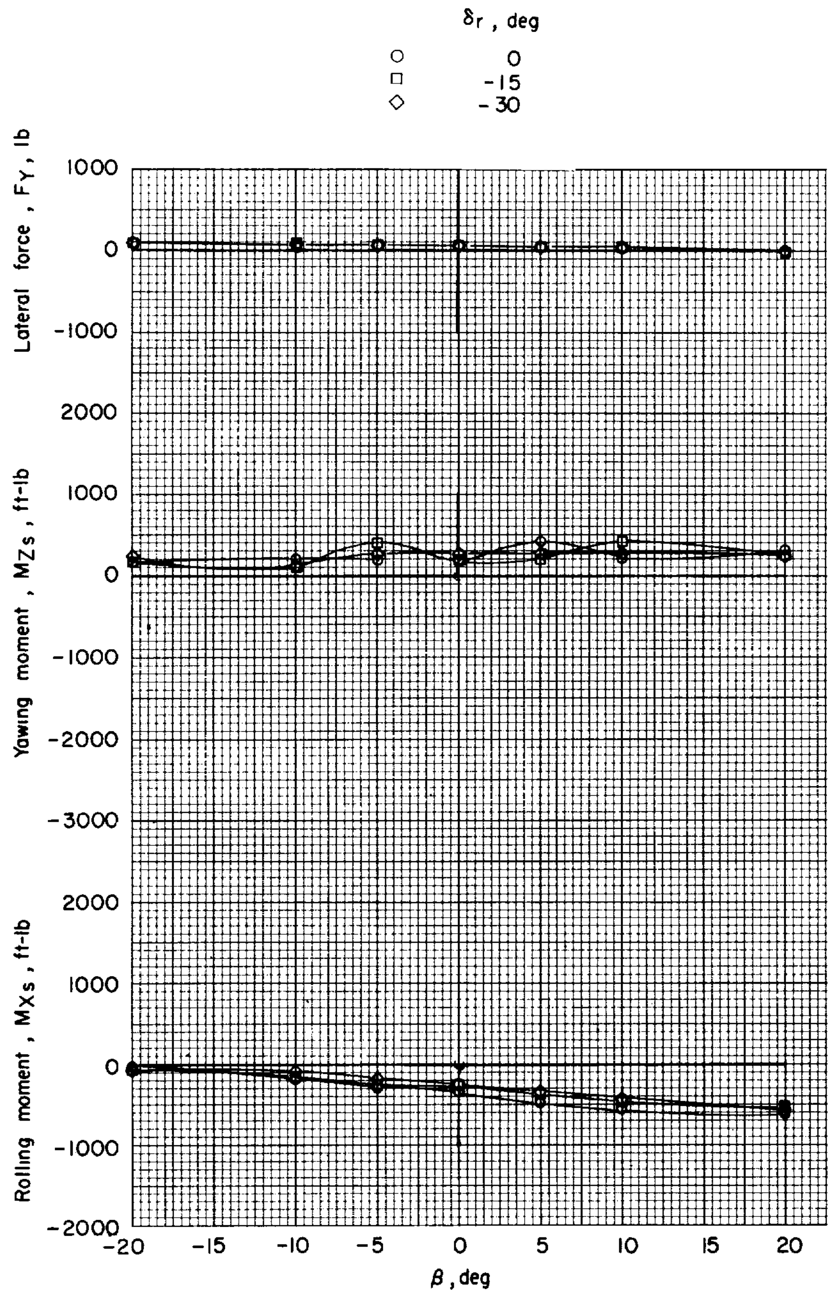
(a) $i_w = 60^o$; V = 15.9 knots.

Figure 10.- Lateral stability and rudder control characteristics for 0.25g acceleration at $\beta = 0^o$. $\delta_a = \alpha = 0^o$.



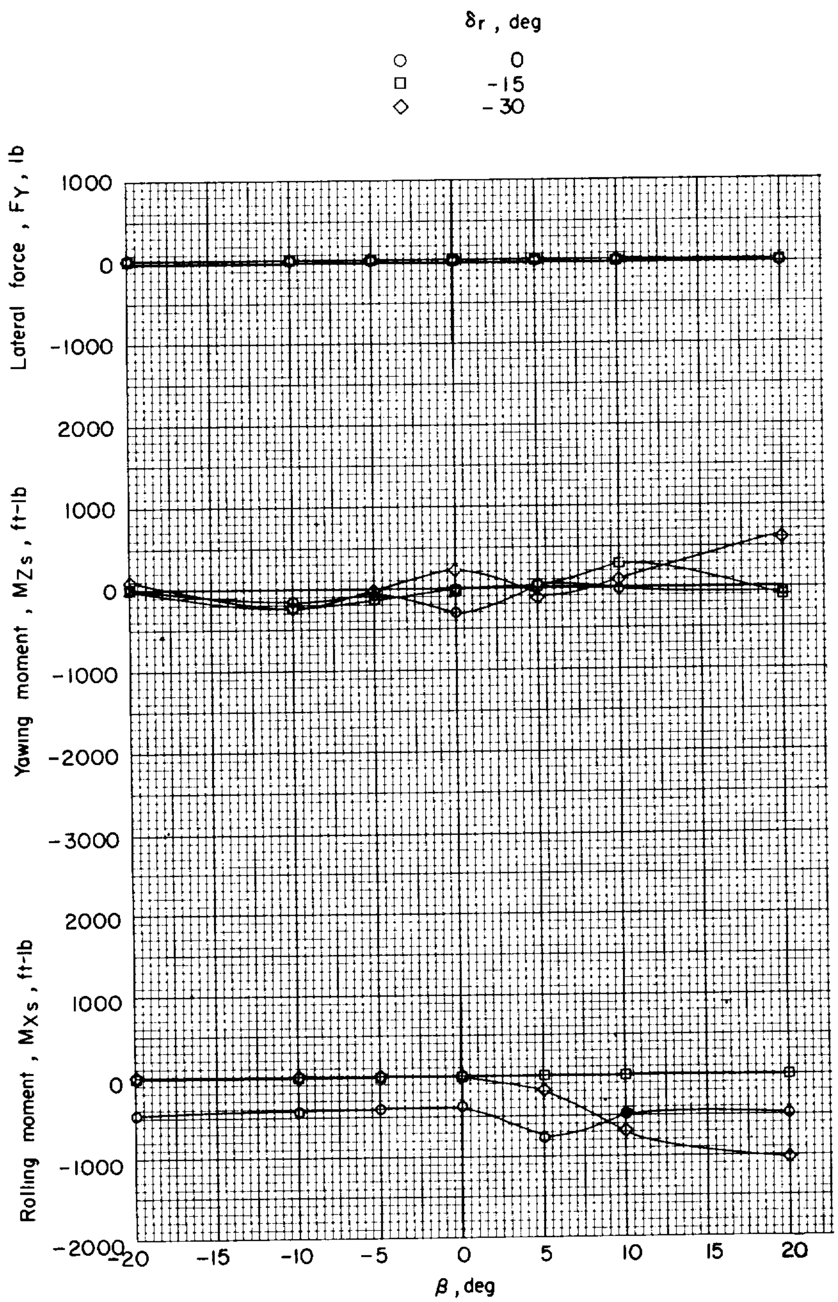
(b) $i_w = 65^o$; V = 12.2 knots.

Figure 10.- Continued.



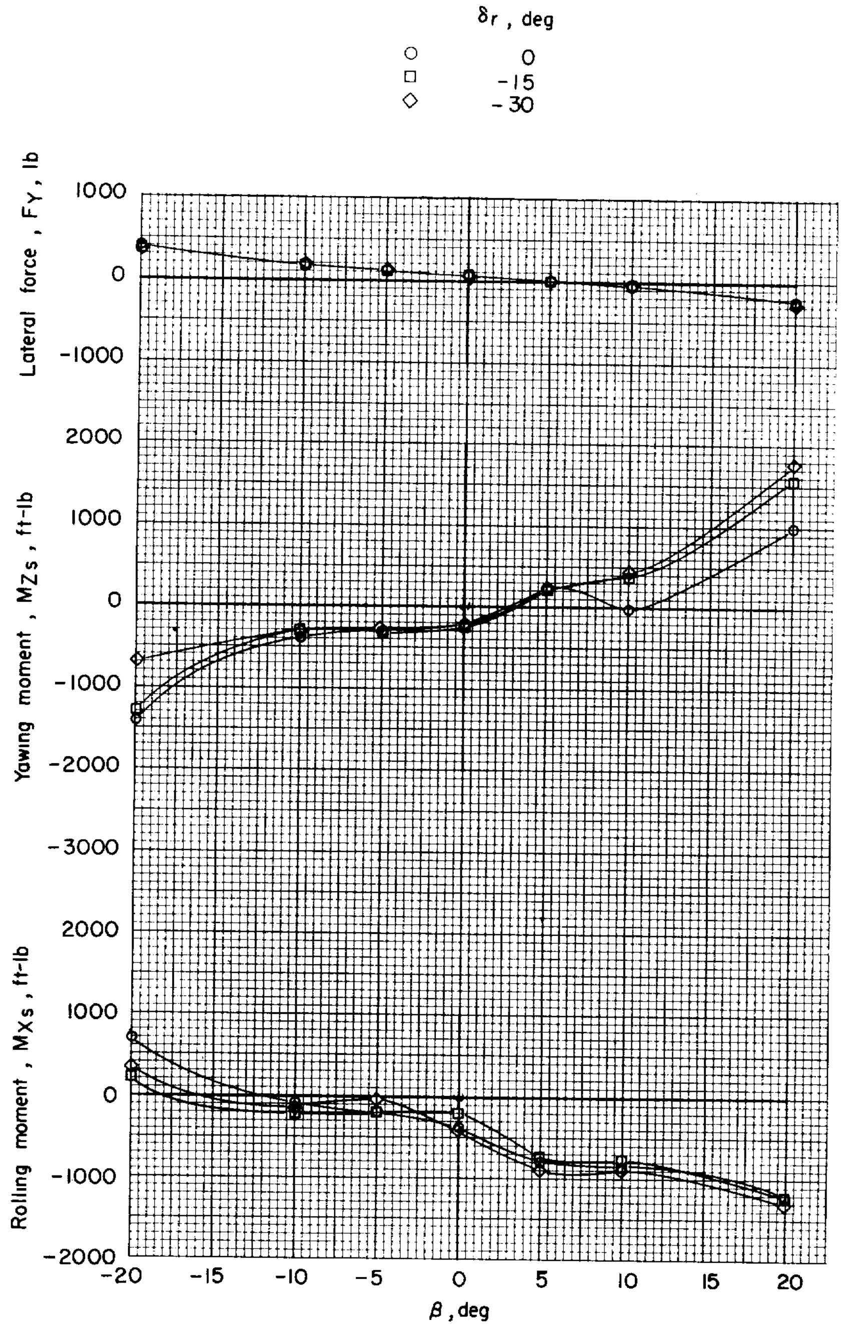
(c) $i_w = 70^{\circ}$; V = 10.2 knots.

Figure 10.- Continued.



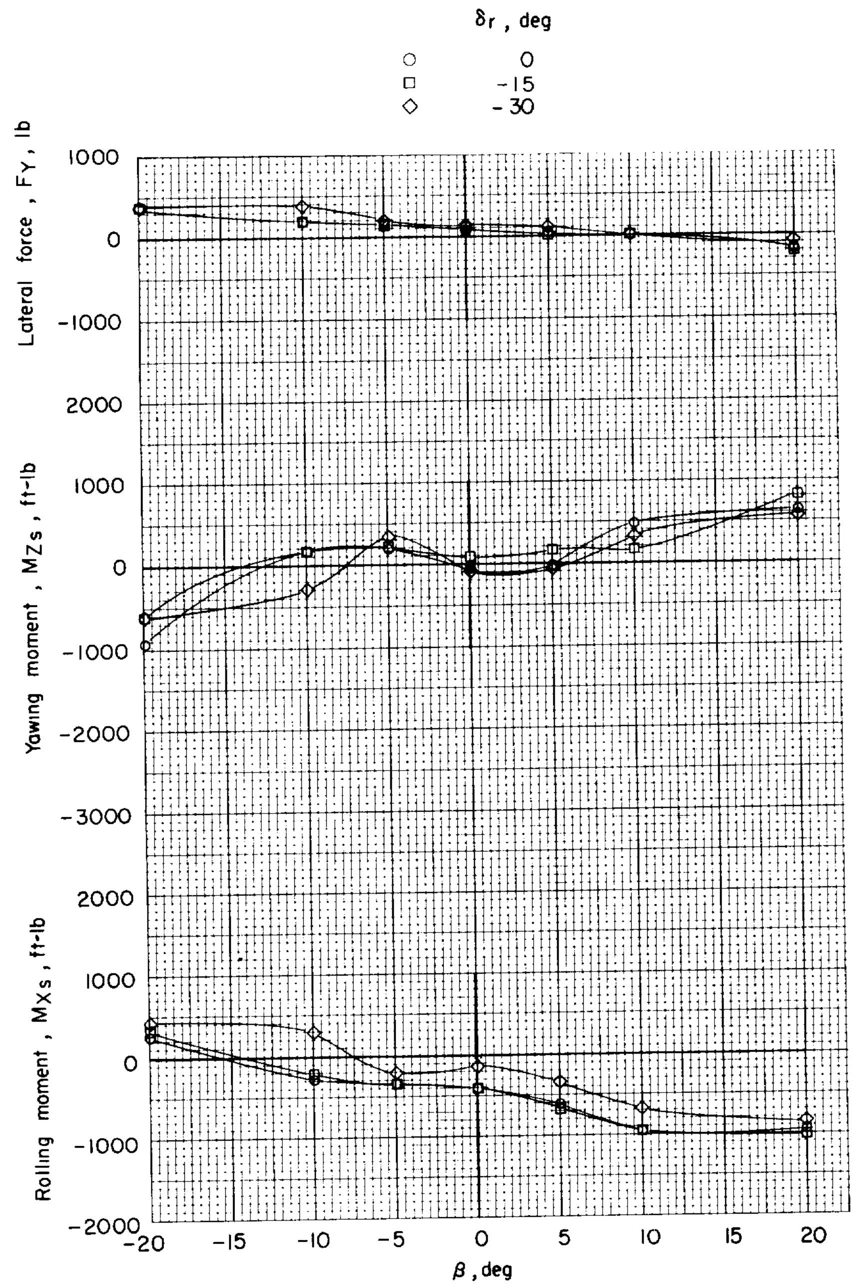
(d) $i_w = 75^{\circ}$; V not determined.

Figure 10.- Concluded.



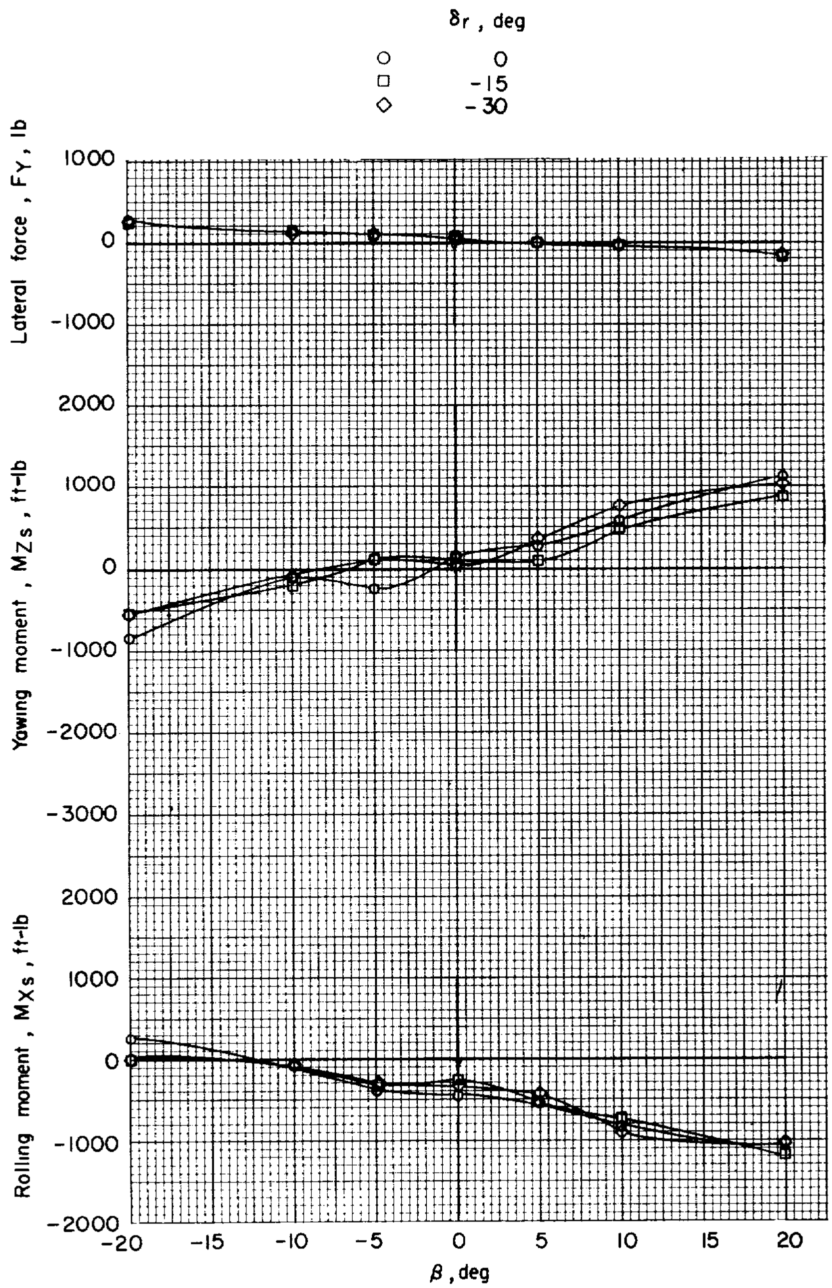
(a) $i_w = 60^\circ$; V = 42.2 knots.

Figure 11.- Lateral stability and rudder control characteristics for 0.25g deceleration at $\beta = 0^\circ$. $\delta_a = \alpha = 0^\circ$.



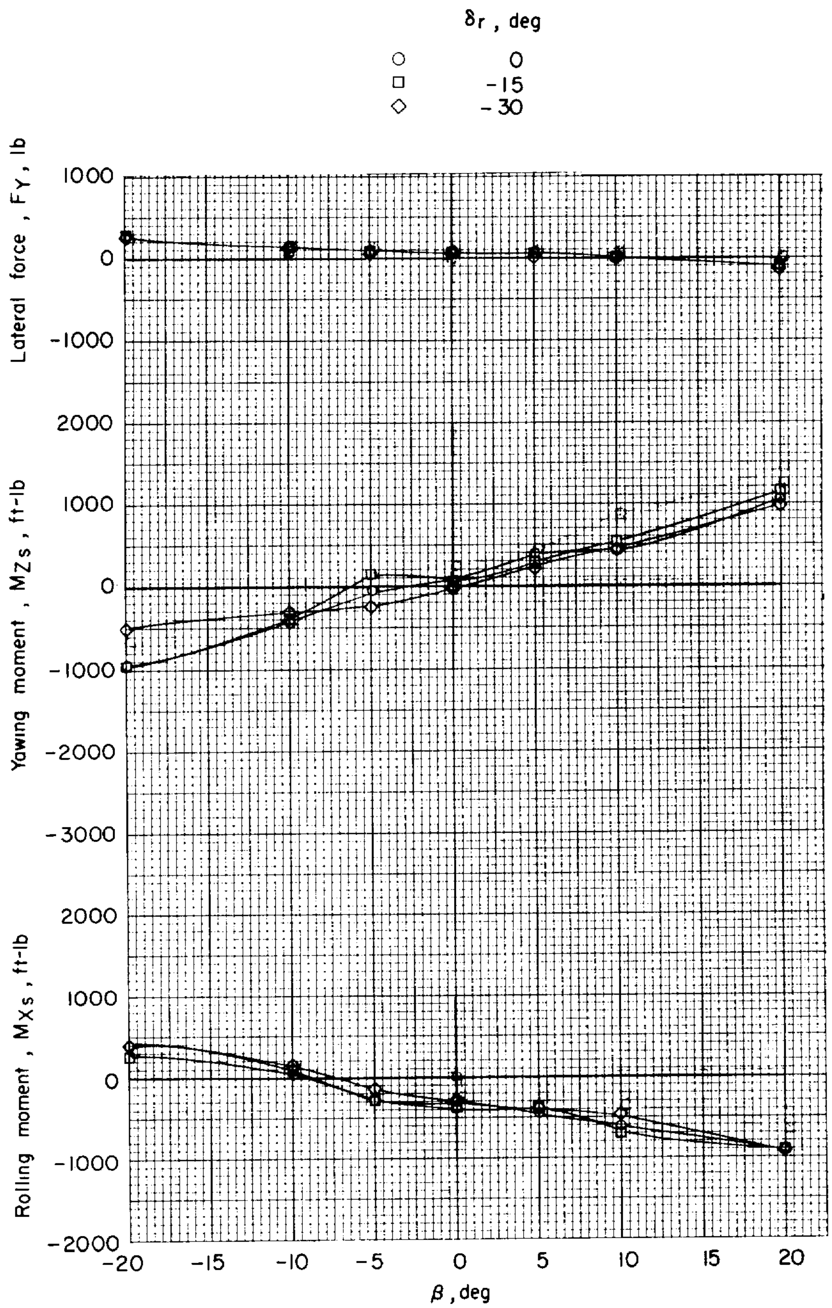
(b) $i_w = 65^{\circ}$; V = 37.6 knots.

Figure 11.- Continued.



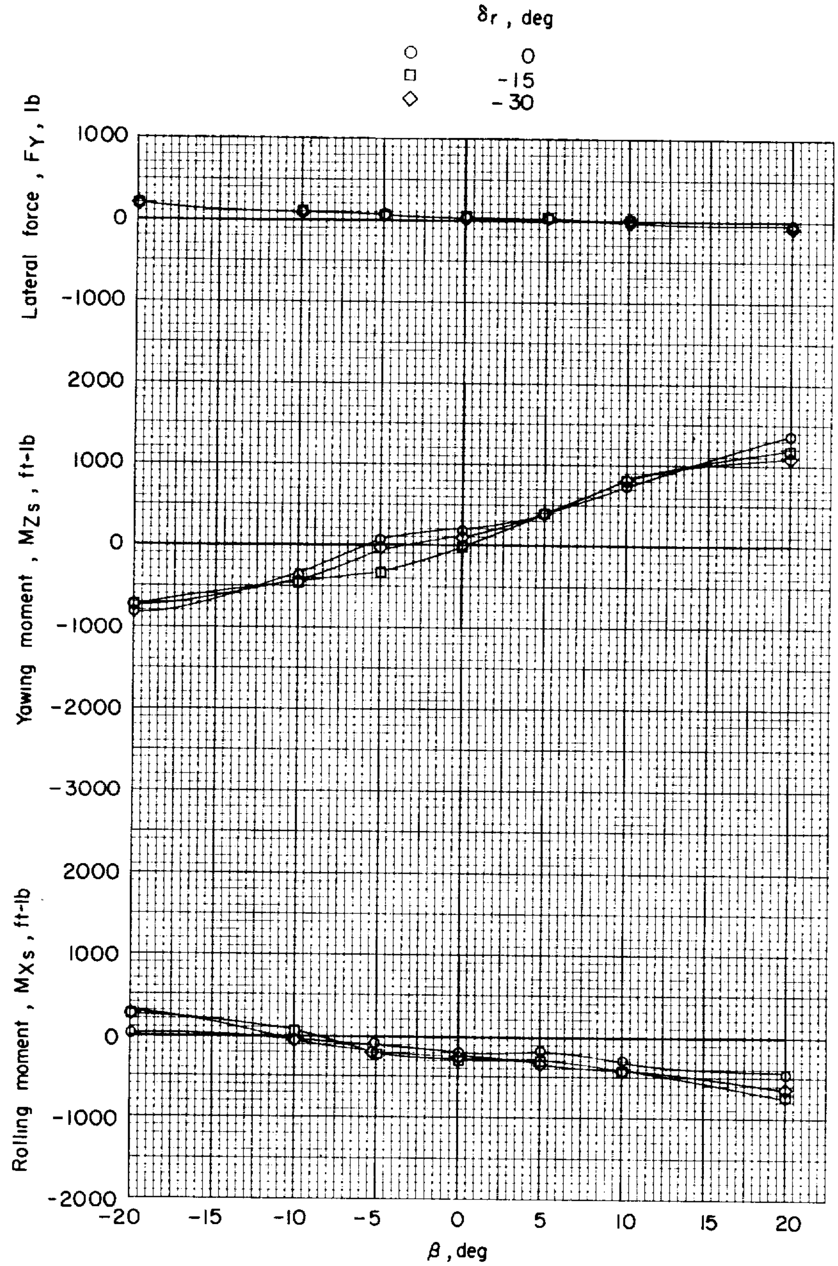
(c) $i_w = 70^{\circ}$; V = 31.5 knots.

Figure 11.- Continued.



(d) $i_w = 75^{\circ}$; V = 28.9 knots.

Figure 11.- Continued.



(e) $i_w = 80^{\circ}$; V = 25.0 knots.

Figure 11.- Concluded.

NASA TN D-390
National Aeronautics and Space Administration.
AERODYNAMIC CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT-WING VTOL AIRCRAFT AT HIGH ANGLES OF WING INCIDENCE. Louis P. Tosti. September 1960. 42p. OTS price, $1.25. (NASA TECHNICAL NOTE D-390)

The model had two propellers with hinged (flapping) blades mounted on the wing which could be tilted from 4° incidence for forward flight to 86° for hovering flight. The investigation included measurements of longitudinal stability characteristics for the low-speed portions of the transition range from 60° to 84° wing incidence at zero acceleration (steady level flight) and of lateral stability and control characteristics for wing incidences from 60° to 80° for a range of conditions simulating zero acceleration, 0.25g forward acceleration, and 0.25g deceleration.

(Initial NASA distribution: 1, Aerodynamics, aircraft; 3, Aircraft; 50, Stability and control.)

Copies obtainable from NASA, Washington

I. Tosti, Louis P.
II. NASA TN D-390

NASA

NASA TN D-390
National Aeronautics and Space Administration.
AERODYNAMIC CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT-WING VTOL AIRCRAFT AT HIGH ANGLES OF WING INCIDENCE. Louis P. Tosti. September 1960. 42p. OTS price, $1.25. (NASA TECHNICAL NOTE D-390)

The model had two propellers with hinged (flapping) blades mounted on the wing which could be tilted from 4° incidence for forward flight to 86° for hovering flight. The investigation included measurements of longitudinal stability characteristics for the low-speed portions of the transition range from 60° to 84° wing incidence at zero acceleration (steady level flight) and of lateral stability and control characteristics for wing incidences from 60° to 80° for a range of conditions simulating zero acceleration, 0.25g forward acceleration, and 0.25g deceleration.

(Initial NASA distribution: 1, Aerodynamics, aircraft; 3, Aircraft; 50, Stability and control.)

Copies obtainable from NASA, Washington

I. Tosti, Louis P.
II. NASA TN D-390

NASA

NASA TN D-390
National Aeronautics and Space Administration.
AERODYNAMIC CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT-WING VTOL AIRCRAFT AT HIGH ANGLES OF WING INCIDENCE. Louis P. Tosti. September 1960. 42p. OTS price, $1.25. (NASA TECHNICAL NOTE D-390)

The model had two propellers with hinged (flapping) blades mounted on the wing which could be tilted from 4° incidence for forward flight to 86° for hovering flight. The investigation included measurements of longitudinal stability characteristics for the low-speed portions of the transition range from 60° to 84° wing incidence at zero acceleration (steady level flight) and of lateral stability and control characteristics for wing incidences from 60° to 80° for a range of conditions simulating zero acceleration, 0.25g forward acceleration, and 0.25g deceleration.

(Initial NASA distribution: 1, Aerodynamics, aircraft; 3, Aircraft; 50, Stability and control.)

Copies obtainable from NASA, Washington

I. Tosti, Louis P.
II. NASA TN D-390

NASA

NASA TN D-390
National Aeronautics and Space Administration.
AERODYNAMIC CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT-WING VTOL AIRCRAFT AT HIGH ANGLES OF WING INCIDENCE. Louis P. Tosti. September 1960. 42p. OTS price, $1.25. (NASA TECHNICAL NOTE D-390)

The model had two propellers with hinged (flapping) blades mounted on the wing which could be tilted from 4° incidence for forward flight to 86° for hovering flight. The investigation included measurements of longitudinal stability characteristics for the low-speed portions of the transition range from 60° to 84° wing incidence at zero acceleration (steady level flight) and of lateral stability and control characteristics for wing incidences from 60° to 80° for a range of conditions simulating zero acceleration, 0.25g forward acceleration, and 0.25g deceleration.

(Initial NASA distribution: 1, Aerodynamics, aircraft; 3, Aircraft; 50, Stability and control.)

Copies obtainable from NASA, Washington

I. Tosti, Louis P.
II. NASA TN D-390

NASA

NASA TN D-390
National Aeronautics and Space Administration.
AERODYNAMIC CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT-WING VTOL AIRCRAFT AT HIGH ANGLES OF WING INCIDENCE. Louis P. Tosti. September 1960. 42p. OTS price, $1.25. (NASA TECHNICAL NOTE D-390)

The model had two propellers with hinged (flapping) blades mounted on the wing which could be tilted from 4° incidence for forward flight to 86° for hovering flight. The investigation included measurements of longitudinal stability characteristics for the low-speed portions of the transition range from 60° to 84° wing incidence at zero acceleration (steady level flight) and of lateral stability and control characteristics for wing incidences from 60° to 80° for a range of conditions simulating zero acceleration, 0.25g forward acceleration, and 0.25g deceleration.

(Initial NASA distribution: 1, Aerodynamics, aircraft; 3, Aircraft; 50, Stability and control.)
Copies obtainable from NASA, Washington

I. Tosti, Louis P.
II. NASA TN D-390

NASA

NASA TN D-390
National Aeronautics and Space Administration.
AERODYNAMIC CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT-WING VTOL AIRCRAFT AT HIGH ANGLES OF WING INCIDENCE. Louis P. Tosti. September 1960. 42p. OTS price, $1.25. (NASA TECHNICAL NOTE D-390)

The model had two propellers with hinged (flapping) blades mounted on the wing which could be tilted from 4° incidence for forward flight to 86° for hovering flight. The investigation included measurements of longitudinal stability characteristics for the low-speed portions of the transition range from 60° to 84° wing incidence at zero acceleration (steady level flight) and of lateral stability and control characteristics for wing incidences from 60° to 80° for a range of conditions simulating zero acceleration, 0.25g forward acceleration, and 0.25g deceleration.

(Initial NASA distribution: 1, Aerodynamics, aircraft; 3, Aircraft; 50, Stability and control.)
Copies obtainable from NASA, Washington

I. Tosti, Louis P.
II. NASA TN D-390

NASA

NASA TN D-390
National Aeronautics and Space Administration.
AERODYNAMIC CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT-WING VTOL AIRCRAFT AT HIGH ANGLES OF WING INCIDENCE. Louis P. Tosti. September 1960. 42p. OTS price, $1.25. (NASA TECHNICAL NOTE D-390)

The model had two propellers with hinged (flapping) blades mounted on the wing which could be tilted from 4° incidence for forward flight to 86° for hovering flight. The investigation included measurements of longitudinal stability characteristics for the low-speed portions of the transition range from 60° to 84° wing incidence at zero acceleration (steady level flight) and of lateral stability and control characteristics for wing incidences from 60° to 80° for a range of conditions simulating zero acceleration, 0.25g forward acceleration, and 0.25g deceleration.

(Initial NASA distribution: 1, Aerodynamics, aircraft; 3, Aircraft; 50, Stability and control.)
Copies obtainable from NASA, Washington

I. Tosti, Louis P.
II. NASA TN D-390

NASA

NASA TN D-390
National Aeronautics and Space Administration.
AERODYNAMIC CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT-WING VTOL AIRCRAFT AT HIGH ANGLES OF WING INCIDENCE. Louis P. Tosti. September 1960. 42p. OTS price, $1.25. (NASA TECHNICAL NOTE D-390)

The model had two propellers with hinged (flapping) blades mounted on the wing which could be tilted from 4° incidence for forward flight to 86° for hovering flight. The investigation included measurements of longitudinal stability characteristics for the low-speed portions of the transition range from 60° to 84° wing incidence at zero acceleration (steady level flight) and of lateral stability and control characteristics for wing incidences from 60° to 80° for a range of conditions simulating zero acceleration, 0.25g forward acceleration, and 0.25g deceleration.

(Initial NASA distribution: 1, Aerodynamics, aircraft; 3, Aircraft; 50, Stability and control.)
Copies obtainable from NASA, Washington

I. Tosti, Louis P.
II. NASA TN D-390

NASA